THE REGULATION OF THE ZAMBEZI IN MOZAMBIQUE:

A STUDY OF THE ORIGINS AND IMPACT OF THE CABORA BASSA PROJECT

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ABSTRACT

The Cabora Bassa Dam regulates the discharge of the lower Zambezi. Its principal output, hydroelectric energy, sold under a bulk supply contract with the Republic of South Africa, brings little direct benefit to the people of Mozambique. The Mozambican authorities are limited in their ability to influence the operation of the dam both by the terms of the power contract and by various technical, economic and political constraints. Hydrological models indicate the practical effects of such constraints and show the extent to which the project's operation is influenced by river regulation upstream. The difficulty of optimizing its operation to provide additional outputs would be increased by the construction of the North Bank Power Station. The characteristics of the scheme, and of the surrounding regions, restrict the establishment of alternative markets for Cabora Bassa's energy within Mozambique and in neighbouring countries. In the long-term, the accumulation of sediment in Lake Cabora Bassa and the project's social and environmental impacts are likely to become increasingly significant in determining the value of the project.

The complex and far-reaching changes induced by the construction of the Cabora Bassa Dam will have considerable influence over the future development of the lower Zambezi valley. The options open to Mozambique are restricted by the constraints of the system and the information and resources available, but some benefit could be gained through co-operation with other basin states. The general lessons provided by the Cabora Bassa Project are applicable to large water regulation projects in other under-developed regions.

DECLARATION

I delcare that this thesis has been composed by myself and that the work contained within it is my own.

17 June 1983

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GLOSSARY OF SELECTED TERMS

aldeia comunal	-	communal village (established by Frelimo).
aldeamento	-	fortified or strategic village (established by Portuguese authorities).
annual maximum flood	-	the value of the highest discharge occuring in a given time (say a one-day, ten-day or one-month period) in a given hydrological year.
annual maximum flood series	-	a data series comprising the annual maximum floods in a succession of hydrological years.
conto	-	monetary value equal to one thousand Portuguese escudos.
cumulative discharge and rainfall curves	-	curves showing cumulative totals of a given parameter, from a given date, against time.
data record	-	a set of values of a given parameter measured at a given location.
data series	-	a continuous set of values of a given parameter which may include values derived from one or more record and values obtained by such techniques as data generation and catchment modelling.
design flood	-	the most severe flood event which the project has been designed to withstand without excessive damage being sustained.
discharge	-	the volume of water passing a given point in a river or channel in a given period of time.
drawdown zone	-	the shoreline zone of a reservoir bounded by its highest and lowest operating levels.
firm power	-	the power output from a hydroelectric project which can be provided continuously with a relatively high level of certainty (strictly the level of probability should be stated).
load factor (l.f.)	-	the ratio of the mean power output, from an electrical generating station, to its installed capacity.

'natural' discharges	-	the estimated values of river discharges which would have occurred if no river regulation had taken place.
prazo	-	a parcel of land over which the Portuguese state granted wide powers of jurisdiction to individual settlers.
rating curve	-	a graph showing an assumed or measured relationship between river discharge and river level at a particular river gauging station.
return period	-	a common means of expressing the estimated probability of occurrence of a given hydrological event - an event which has a probability of occuring once in one hundred years is said to have a return period of one hundred years.
rule curve	-	a set of reservoir levels for different times of the year which is used in a specified manner to determine current reservoir operating procedures.
runoff coefficient	-	the proportion of the precipitation over a given catchment which is released as surface flow.
run-of-river	-	a type of hydroelectric power station which has no storage capacity of its own to regulate the discharges of the river.
secondary energy	-	energy generated by a hydroelectric power station in excess of that provided by its firm power output.
sediment rating curve	-	a curve showing the assumed relationship between sediment concentration (or total sediment load) against river level (or discharge) at a given location.
target power output	-	the output which the operators of a hydroelectric scheme are seeking to achieve as a guide for determining their operating policies (the value may be higher than the firm power output).
threshold discharge	-	a term used by RPT, in reference to a proposed operating procedure for the Cabora Bassa Dam, for the maximum discharge which may be made from the dam without causing significant flood damage downstream.

ABBREVIATIONS AND ACRONYMS

ASCE	-	American Society of Civil Engineers.
BEES	-	Brigada de Estudos Económico-Socias (Brigade for Socio-Economic Studies, of the MFPZ).
CAPC	-	Central African Power Corporation.
DNA	-	Direcção Nacional de Águas (National Water Directorate of Mozambique).
DVC	-	Damodar Valley Corporation (India).
Escom	-	Electricity Supply Commission (of the RSA).
FAO	-	Food and Agriculture Organization (of the United Nations).
Frelimo	-	Frente de Libertação de Moçambique (Mozambique Liberation Front).
GEV	-	General extreme value (an algebraic function used in the analysis of flood frequencies).
GPZ	-	Gabinete do Plano do Zambeze (Bureau of the Zambezi Plan).
HCB	-	Companhia Hidroeléctrica do Cabora Bassa (Cabora Bassa Hydroelectric Company).
ICE	-	Institution of Civil Engineers (London).
ICOLD	-	International Commission on Large Dams.
MFPZ	-	Missão de Fomento e Povoamento do Zambeze (The Zambezi Development and Settlement Authority).
OD	-	Over datum (with reference to values of elevation). The datum is, in most cases, approximately sea level although there is no standard datum used throughout the Zambezi basin.
OMVS	-	Organisation pour la Mise en Valeur du Fleuve Senegal (Senegal River Development Authority).
PMF	-	Probable maximum flood.
PMP	-	Probable maximum precipitation.
RPT	-	Rendel, Palmer and Tritton (consulting engineers, London).
RSA	-	Republic of South Africa.
ISIC	-	International Standard Industrial Classification.

SADCC	-	Southern African Development Co-ordination Conference (comprising nine 'front-line' states plus representatives of Namibia).
SCOPE	-	Scientific Committee on Problems of the Environment.
SPA	-	Serviço Provincial de Águas (Provincial Water Service, responsible to the DNA).
SWECO	-	Swedish Consulting Engineers and Architects (comprising eight member firms).
SWPC	-	Shawinigan Water and Power Company (Quebec).
TVA	-	Tennessee Valley Authority.
UDI	-	Unilateral Declaration of Independence.
UNDP	-	United Nations Development Programme.
UNESCO	-	United Nations Educational Scientific and Cultural Organization.
ZAMCO	-	Zambeze Consórcia Hidro-eléctrico (the construction consortium for the Cabora Bassa Project).
ZESCO	-	Zambia Electricity Supply Corporation.

A NOTE ON GEOGRAPHICAL NAMES AND UNITS OF MEASUREMENT

Names of countries: The name Mozambique is, for convenience, used throughout this thesis rather than the Portuguese spelling, Moçambique, or the country's full name since independence, the Republique Popular de Moçambique (People's Republic of Mozambique). Similarly the shortened English names of other countries with independent majority governments are used, for example, Zimbabwe, Zambia and Malawi. Their colonial names, Southern and Northern Rhodesia and Nyasaland, are occasionally used in historical sections where use of their present names would have been misleading. The Republic of South Africa (RSA) has been so named throughout the thesis in order to avoid confusion with the regional name 'southern Africa' and to emphasize the fact that the government which has adopted this name represents only the white minority.

Other place names: The names of a number of towns and cities in Mozambique and Zimbabwe have been changed since the countries became independent. The new names, for example Maputo and Harare, are used except where their use would have been confusing. In other cases, where two or more alternative spellings have been used in the past, an attempt has been made to select the form most widely used at present. The spelling of Cabora Bassa causes particular difficulties. A large number of forms, both hyphenated and unhyphenated, have been published. These include Caoura-Bassa, Karcabassa, Cahourabassa, Queruabassa, Camala-Bassa and numerous others. The form adopted throughout this thesis, Cabora Bassa, is the spelling used most widely in the English-speaking world and is also found in many Portuguese publications and reports. Nevertheless, there are indications that the authorities in Mozambique have recently chosen to adopt the spelling Cahora Bassa or Cahora-Bassa in preference.

Names of rivers: As with other names the principal objective in selecting a particular spelling has been to avoid ambiguity rather than to adhere to a strictly logical naming system. In many cases rivers running through more than one country have been given different names in each country and, in some cases, variations of spelling also occur within a single country. In general, the form used in this thesis is that used most widely in the country which contains the largest proportion of the river's catchment. Thus, Zambezi is used in place of the Portuguese Zambeze or the alternative English spelling Zambesi. Similarly, the names Shire (Portuguese, Chire), Hunyani (Portuguese, Panhame) and Luangwa (Portuguese, Aruangua) have been adopted. The Luangwa presents particular difficulties because of the existence of other rivers with similar names in the Zambezi basin and because various archiac spellings are used in older documents. The term 'the lower Zambezi basin (or valley)' is not applied with precision in the thesis but is generally used to refer to the valley downstream of Cabora Bassa.

Units of measurement: Metric units are used throughout the thesis following the S.I. system. Where original sources have used other units the writer has made the appropriate conversions. An indication of where such conversions have been necessary has generally been given in the text. The letters k, M, G and T have been incorporated into units to indicate factors of 10^3 in the normal way: kilo (10^3), Mega (10^6), Giga (10^9) and Tera (10^{12}). However, for clarity, their use has been avoided for areas and volumes. ('One million square metres' is written '10^6 m^2').

The decimal point: A single point placed on the line indicates the decimal place (eg. 1.25). No punctuation is used to indicate thousands although appropriate spaces have been left (eg. 12 500). This notation is used to avoid confusion between the system generally used in Britain and that used in Portugal and Mozambique where the decimal place is indicated by a comma and thousands by a point.

Currency: Monetary values are given in the currency used in original sources. In order to provide a means of comparison they have also been converted to American dollars using exchange rates in operation at the time of the particular transaction. These values are given in parentheses. No attempt has been made to convert them to present or constant prices. Prior to 1975 the currency used in Mozambique was the Portuguese *escudo*, one thousand *escudos* being equal to one *conto*.

After Independence the Mozambican *escudo* was no longer tied to that of Portugal. It has since been renamed the *metical*.

Hydrological years: In regions which show a clear seasonal rainfall pattern it is general practice to define a 'hydrological year' and to use this rather than the calendar year, as the basis for hydrological calculations. The start of the hydrological year is chosen to coincide with, or slightly precede, the beginning of the wet season. In the present work, as in most previous studies of the Zambezi basin, a hydrological year starting on 1 October is used. Thus, 'the year 1963/4' indicates the hydrological year from 1 October 1963 to 30 September 1964.

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My research brought me into conversation and correspondence with a large number of people from universities, governmental and international agencies, research institutions, electricity supply companies and firms of consulting engineers in Britain and Mozambique, as well as in other countries in southern Africa, Europe and North America. Where I have made direct use of their work, full details are supplied in the References and Bibliography. To these people and all who responded to my various requests for information I am most grateful. Special mention should be made of the co-operation which I received from the consultants Rendel, Palmer and Tritton and SWECO and for the help I received, during my time in Zambia, from my parents and from Mr Abou Zeid, Mr B A Mian, Dr T C Sharma and Prof. G J Williams.

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INTRODUCTION

> The civil engineer should recognise the many factors which may defy expression in direct money values, particularly those which arise from effects on a community's way of life.[1] (Institution of Civil Engineers, London: 1973 statement on social responsibilities).

> The entire works under study in the River Zambezi, along its banks and in its delta are extraordinarily complex even if the hydraulic aspects alone are considered ... They become still more complex when other related aspects are considered for the development of the region, such as minerals and agriculture.

> The object of the works planned is to build a logical and ordered whole which permits the best possible benefit from the economic potential of the region of the Zambezi, an integration which is difficult to plan given the vastness of the problem and the number of factors to be considered. (*Esquema Geral,* 22.1, p1*).

On 4th December 1974, sixteen years after the completion of the Kariba Dam, a dam in the narrow and remote Cabora Bassa Gorge in Mozambique was finally closed and a vast new reservoir began to fill. The creation of this second major impoundment on the Zambezi marked the culmination of a long period of planning and preparation. The idea of constructing a dam at Cabora Bassa had been suggested possibly as much as a hundred years earlier although it was not until 1956 that the first direct measures were taken to implement the idea. The detailed investigations which were undertaken from 1956 onwards were directed not only towards plans for the dam itself but also towards the economic development of the whole Zambezi valley. Nevertheless, despite the size of this project and the extent of the preparation which had taken place, few people outside Portugal had heard the name Cabora Bassa before 1968. Furthermore very little had been written about the project beyond what was contained in multi-volumed reports prepared by the Portuguese planners and engineers.

By contrast, between 1968 and 1975 the Cabora Bassa Dam was the focus of considerable publicity. In the war that was then taking place between the guerrillas of Frelimo** and the Portuguese armed forces,

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* For details of references taken from the volumes of *Relatório Preliminar, Esquema Geral* and *Plano Geral* see Bibliography 1.

** *Frente de Libertação Moçambique* (Mozambique Liberation Front).

the Cabora Bassa Dam came to be seen, by many, as a symbol and an instrument of Portugal's continuing domination of the people of Mozambique. Opposition to the project was expressed through direct military action, through diplomatic pressure on governments associated with the financing and construction of the dam and through the writings of academics and others sympathetic the idea of an independent government in Mozambique.

In Portuguese publications an attempt was made to counter these political arguments by pointing to development work which was being undertaken in the basin and, in particular, to the benefits which, they believed, would accrue to all the people of the region once the completed dam had begun to act as the intended driving force behind economic development. Such arguments even persuaded a few of those opposed to the project on political grounds to venture the suggestion that the dam could be an undoubted asset once the people of Mozambique had gained their independence.

Technical publications, during this period, gave the project considerable publicity in language which, at times, verged on the euphoric. Writers concentrated on the project's technical merits - the choice of location for the dam, the skill shown in overcoming various difficulties in construction (including those resulting from the armed conflict), the size of the power installation (ranking fifth in output in the world at the time), the relative cheapness of the electrical energy and the possibilities offered by the newly developed technology using high voltage direct-current transmission which could carry power economically over the 1400 km which separated it from the Republic of South Africa (RSA), a distance which, ten years earlier, would have been virtually unthinkable.

The impoundment of Cabora Bassa Lake began barely six months before Mozambique's Independence Day. Thereafter, for a time, the Cabora Bassa Project returned to relative obscurity in the outside world. Even in Mozambique, the Government appears, at first, to have been prepared to allow the project to continue under the provisions for its operation and control which had been laid down in agreements made with Portugal at the time of independence. Such a policy would have enabled Mozambique to concentrate its limited resources of technical and administrative personnel in solving the more immediate economic and political problems with which it was faced. At the same time, in major political speeches, the Government's attitude towards the Cabora Bassa Dam was clearly stated; the dam would be transformed from a symbol of oppression to a symbol of liberation and it would enable the people of Mozambique, in due course, to achieve economic prosperity and independence.

This, in brief summary, was the situation at the beginning of 1978 when the writer began the work on which this thesis is based. The period of relative inactivity seemed to offer an ideal opportunity for careful evaluation of a number of important questions concerning the Cabora Bassa Dam and the regulation of the Zambezi. Mozambique's complete dependence on energy sales to a powerful neighbouring country and the contrast between the political motivations and expectations of the people who planned and executed the project and those who, in the event, inherited it provided the possible basis for an interesting case study into the extent to which the choice of a particular technology, in this case a large hydroelectric project, might be influenced by, or exert an influence over, political factors. Moreover, the Cabora Bassa Dam provided the opportunity to study in detail the problems faced by an underdeveloped country in Africa in regulating the discharge from a large international river basin. The questions were by no means purely academic: sooner or later plans to expand the consumption of electrical energy in Mozambique and to develop agriculture in the Zambezi valley would compel the authorities to look more closely at the implications of the present reservoir operating procedures which were geared soley towards the production of power for the RSA. It was intended that this work would provide a foundation which might assist the authorities in Mozambique in resolving practical questions of this nature and alert them to the difficulties which might face them. In addition, it was hoped that some of the conclusions reached might find practical application in the regulating of river basins elsewhere.

Since January 1978 a series of largely unforeseen events has served to awaken new interest in the Zambezi valley and the Cabora Bassa

Project. In March and April 1978 severe flooding occurred downstream of the Cabora Bassa Dam. As a result the Mozambican authorities commissioned the British firm of consulting engineers, Rendel, Palmer and Tritton (RPT), to investigate the possibility of controlling floods and of installing a flood warning system downstream of the dam. At the other extreme, a period of drought in 1979 and 1980 affected many people in the Zambezi valley and awoke concern over dependence on rain-fed agriculture.

On the alluvial plain, a Soviet team of experts started investigations into the possibility of constructing five large irrigation projects and, in addition, a United Nations consultant undertook a study of the possibility of integrated development of the natural resources of the Marromeu Reserve. Ambitious plans to expand the output of coal from the mine of Moatize led to renewed interest in the possibility of developing the Zambezi as a navigable waterway. The British firm of accountants, Coopers and Lybrand, was commissioned to undertake an economic study of various transportation alternatives. In July 1980, international consortia were invited to submit preliminary tender proposals for the construction of Cabora Bassa Stage Two - the North Bank Power Station (see Appendix 5). Subsequently, SWECO* was commissioned, by *Electricidade de Moçambique,* to undertake feasibility studies for the project. Meanwhile, a French and Italian consortium had won a contract to build electrical transmission lines linking Cabora Bassa with principal urban and industrial centres in northern Mozambique. Future energy planning was complicated, first by the repeated sabotage, from December 1980 onwards, of the transmission lines from Cabora Bassa to the RSA and, secondly, by the announcement towards the end of 1981 that Zimbabwe would build the second stage of the Wankie Thermal Power Station rather than buy power from a new power station at Cabora Bassa. The construction of a road bridge across the Zambezi at Caia, State intervention in the Sena Sugar Estates and the creation, with Bulgarian aid, of a flotilla company on Cabora Bassa Lake are among the other significant events which have occurred in the Zambezi basin during the course of the present study. Finally,

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* SWECO: Swedish Consulting Engineers and Architects (comprising eight member firms).

Zimbabwe's Independence, in April 1980, and the new political and economic possibilities offered through Mozambique's participation in the newly-formed Southern African Development Co-ordination Conference (SADCC) have brought fresh dimensions to the international relationships governing the development of the Zambezi basin's resources.

Although the changes, which occurred since 1978, did not radically alter the original objectives of the present study they served to awaken fresh interest in the development of the basin and brought to the fore questions which had previously been regarded as being only of long-term interest. The changes have, on the one hand, added to the complexity of the work in hand by increasing the number of areas for which issues of immediate relevance have demanded detailed consideration. These have frequently had to be accommodated within, and have influenced, the conclusions reached in research already completed. On the other hand, the changes have brought considerable benefit by providing additional information which has enabled results and conclusions of a more specific and less speculative nature to be reached. The additional information is contained in various official reports prepared since 1978, the majority of which were undertaken by foreign consultants. A brief description of these official reports is included as part of the review of the principal information sources which is included later in this introduction.

The geography of the Zambezi basin

The catchment of the Zambezi, covering an estimated area of 1.3×10^6 km^2, forms the third largest river system in Africa. The largest proportion of the basin lies in Zambia but appreciable areas also lie in Angola, Malawi, Mozambique and Zimbabwe. In addition, small parts lie in Botswana, Namibia, Tanzania and, according to some sources, Zaire, see Figure 1. Table 1, based on approximate calculations made by the writer, indicates the basin's main political sub-divisions and the proportion of each of the principal basin states lying within the basin. The precise figures may be open to dispute, particularly with regard to the inclusion of the Chobe catchment which some authorities have suggested makes no significant hydrological contribution to the Zambezi system[2].

Figure 1

THE ZAMBEZI BASIN

showing principal tributaries and the location of some of the principal hydrometric stations

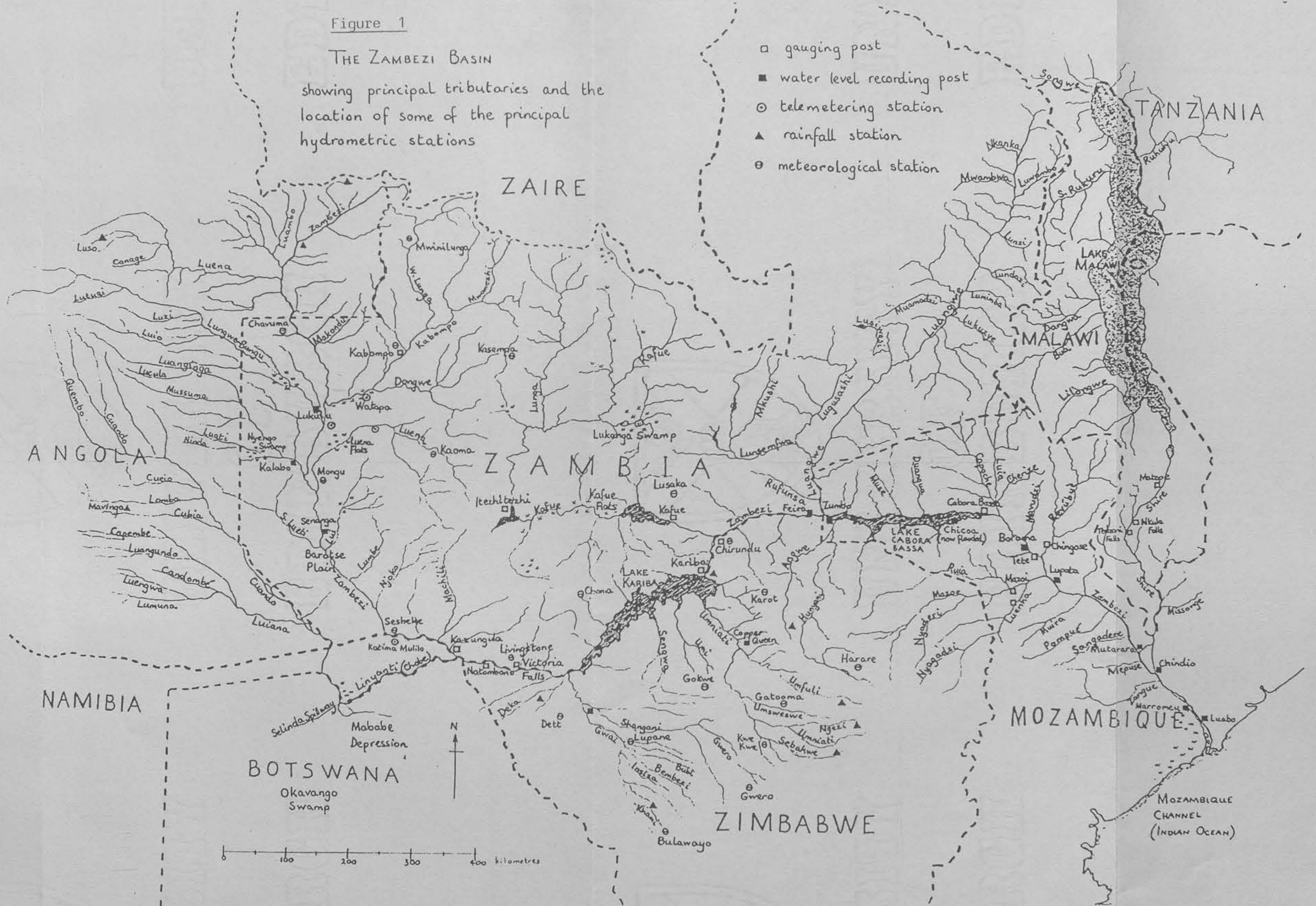


Table 1: Main political sub-divisions of the Zambezi basin

Country	Approximate area covered by Zambezi basin ($km^2 \times 10^3$)	% of total basin area	% of country within basin
Angola	150	12	12
Malawi	120	9	98
Mozambique	140	11	18
Zambia	580	45	77
Zimbabwe	220	17	56

Nevertheless, the figures serve to illustrate the extent of the political fragmentation of the basin and the dominance by rivers of the Zambezi system over the surface water resources of three of the basin states - Malawi, Zambia and Zimbabwe. The river is also of considerable importance to the economy Mozambique both by virtue of the Cabora Bassa Project and as a result of the revenue from sugar production on plantations near its mouth. Furthermore, optimistic predictions have been made about the potential output from further irrigation projects planned for the valley.

The climatic characteristics of the basin are determined by its position in the southern equatorial belt between the 10th and 20th parallels[3]. The southern edge of the inter-tropical convergence zone begins moving across the basin from the north in about November of each year, bringing behind it low pressure which causes extensive rainfall. The zone begins retreating northwards again in about March. As a result, rainfall over the basin has a marked seasonal pattern; the rainy season lasting approximately six months in the north of the basin and from three to four months in the south. Mean annual rainfall is, therefore, highest in the north of the basin and lowest in the south, see Figure 2. In the east of the basin this pattern of rainfall distribution is disrupted by the influence of local topography, the proximity of the Indian Ocean and the circulation patterns associated with the monsoons which approach the basin from the north-east. Nevertheless, a well-defined rainy season still occurs during the warmest months.

Another climatic variable which influences water resources

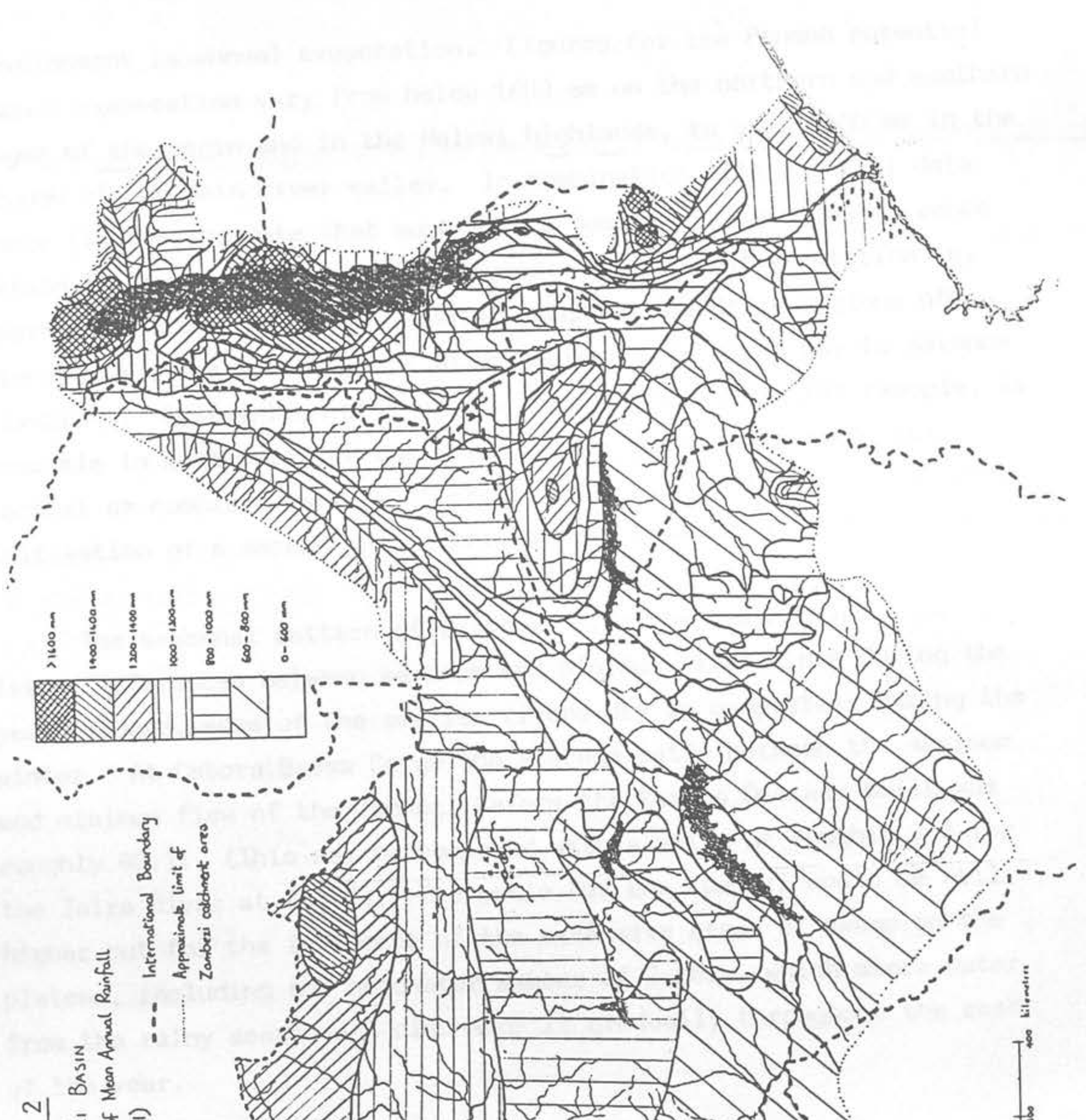


Figure 2
THE ZAMBEZI BASIN
Approximate Distribution of Mean Annual Rainfall
(After Vieira, 1961)

development is annual evaporation. Figures for the Penman potential annual evaporation vary from below 1600 mm on the northern and southern edges of the basin and in the Malawi highlands, to over 1800 mm in the trough of the main river valley. In combination with rainfall data these figures indicate that much of the basin lies in climatic zones within the range sub-arid to sub-humid. The natural vegetation is, therefore, mainly mixed woodland although in the drier regions of Zimbabwe and the lower valley in Mozambique this gives way to savanna grassland. Cultivation of a single annual crop, maize for example, is possible in most parts of the basin during the rainy season, but partial or complete failure of crops sometimes occurs due to drought. Cultivation of a second annual crop almost invariably requires irrigation.

The seasonal pattern of rainfall over the basin gives rise to large differences between maximum and minimum river flows during the year, indeed, some of the smaller rivers dry up completely during the winter. At Cabora Bassa Gorge the average ratio between the maximum and minimum flow of the Zambezi before the Kariba Dam was built was roughly 40:1. (This may be compared with a value of roughly 3:1 for the Zaire River at Inga[4]). The ratio for the Zambezi would be still higher but for the influence of the extensive areas of swamp on the plateau, including the headwater *dambos* of Zambia, which store water from the rainy season and discharge it gradually throughout the rest of the year.

The runoff characteristics in different parts of the basin are not uniform. At one extreme the tributaries from the more arid parts of Zimbabwe show a rapid response to rainfall producing short-duration flood peaks of large magnitude but, since they drain areas of high potential evaporation in which there are few natural storage features, many cease to flow during the dry season. At the other extreme, large areas of floodplain and swamp in the Kafue basin and in the Zambezi catchment upstream of the Victoria Falls act as natural regulators attenuating and delaying flood peaks and sustaining dry season flows. However, the annual evaporation from these swamps is high. The runoff characteristics from the geologically 'mature' valley of the Luangwa are intermediate between these extremes.

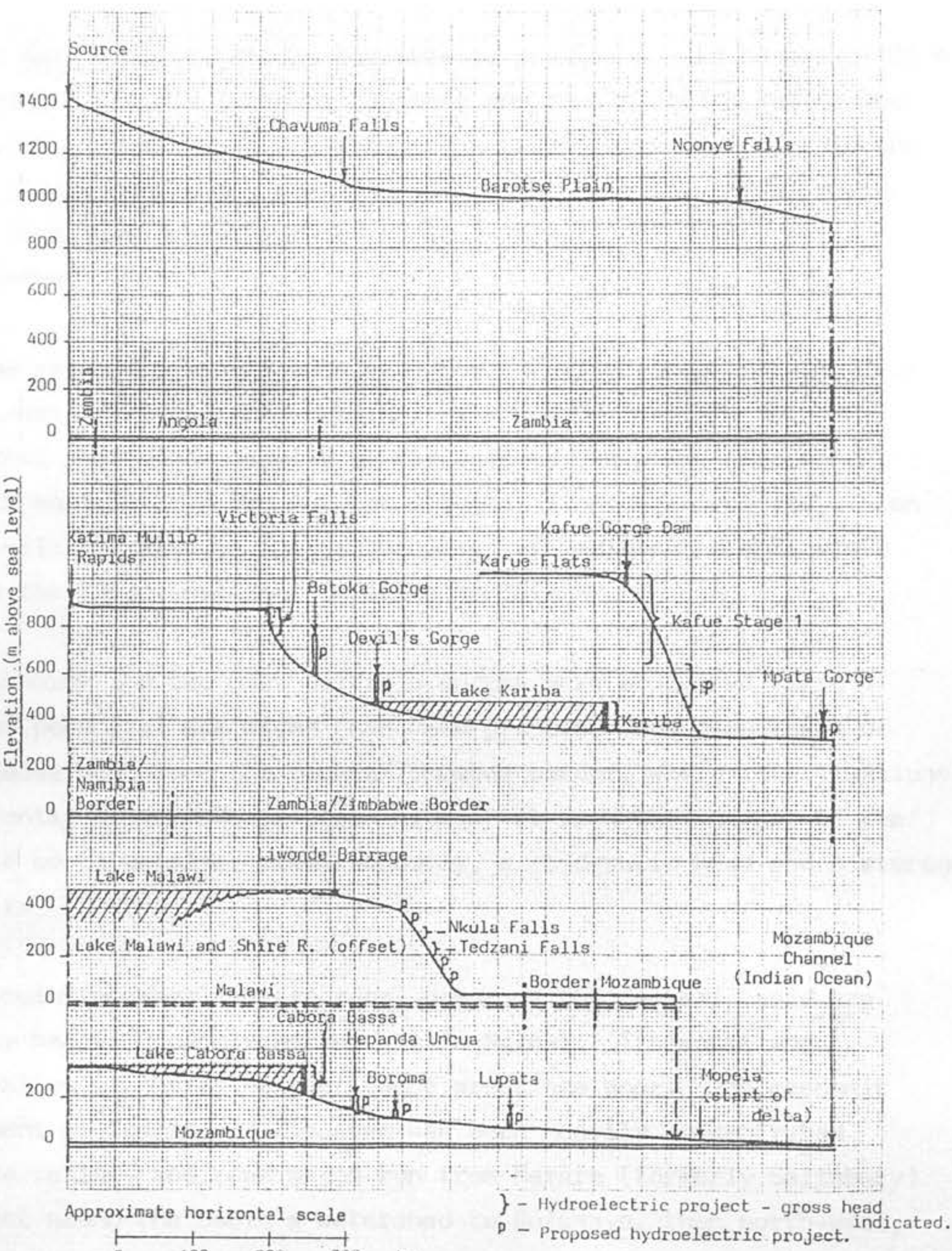
The seasonal variation in river discharge is an important factor in the design of hydroelectric schemes for the basin. These generally require some means of annual storage and the ability, at times, to discharge, rapidly, large quantities of excess flood water.

The most important topographical feature of the Zambezi is that a large part of the basin lies on the central African plateau. The constraints which this imposes on the design of hydroelectric schemes may be illustrated by reference to the main schemes at present in operation. Most of the headwaters are found at an altitude of about 1000 m. After a slow passage through the swamps and floodplains of the plateau the water begins its descent to the coastal plain, and it is during this descent that hydroelectric generation may be possible, see Figure 3.

The sheer drop of just over 100 m at the Victoria Falls is unique in the basin. The relatively simple technology required to tap the water at the top of the falls and lead it through penstocks to a power-house in the gorge at their base, together with the large annual flow of water over the falls, marked this as an obvious site for power generation certainly as early as 1906. At present the installed capacity of 108 MW on the Zambian side is limited by the minimum dry season flow, but it is unlikely that this will be increased by the provision of storage reservoirs because there are no good reservoir sites on the plateau above the falls; such reservoirs as might be created would flood areas of agricultural and ecological importance and, being shallow, would suffer condiderable water loss through evaporation.

Two plateau reservoirs do exist, behind the Itezhitezhi and Kafue dams, for the Kafue Gorge scheme although the annual river flow and the storage capacity required are considerably less than for schemes on the main Zambezi. The hydroelectric potential, in excess of the 900 MW already installed, arises from the river's very rapid descent through a narrow gorge from the plateau to the Zambezi trough. In a distance of about 20 km the river falls 600 m. The tapping of this potential required the excavation of a 10 km long headrace tunnel and an underground powerhouse 500 m below the surface.

Figure 3



Longitudinal profile of the Zambezi, Kafue (part) and Shire Rivers.

Below the Victoria Falls, the main Zambezi flows to the sea in a series of troughs and gorges which cut a wide valley through the plateau. Dams built in these gorges provide the main potential for water storage and hydroelectric generation in the basin.

At Kariba Gorge it was possible to produce a head of about 100 m by building a relatively short concrete dam thus flooding the Gwembe Trough with a man-made lake which, for a time, was the largest in the world. Underground power stations in each bank of the gorge provide a total installed capacity rated at 1266 MW with ultimate provision for a further 300 MW.

The principle is the same at Cabora Bassa Gorge where a maximum head of over 120 m has been obtained by flooding the Chicoa Trough. The nominal installed capacity of the underground power station in the south bank is 2075 MW, but the original proposals included a plan for a similar station in the north bank. If implemented this would increase the total installed capacity to 3825 MW.

Although the two most suitable gorges were exploited first a number of potential dam sites have been proposed both downstream of Cabora Bassa and along the Zambia/Zimbabwe border, where investigations are currently being made at three sites. At each the purpose of the dam would be to develop, simultaneously, a hydraulic head and a storage reservoir.

Population densities in rural areas of the Zambezi basin are generally below 10 people/km^2 except in Malawi. Transport and communications links in many of these areas are poor. The economic development of Zambia and Zimbabwe has been heavily concentrated along the railway and road which run from Harare (formerly Salisbury) south-west along the basin's watershed to Bulawayo, then north-west, through Wankie, to the Victoria Falls, where they cross the Zambezi, north-east to Lusaka and finally north to the Copperbelt. This transport route links the principal urban and industrial centres of Zambia and Zimbabwe as well as the Zambian copper mines, the coal mines around Wankie and the mining centres of the Zimbabwean Midlands. Downstream, the coal mine at Moatize, near Tete, in Mozambique is linked to the

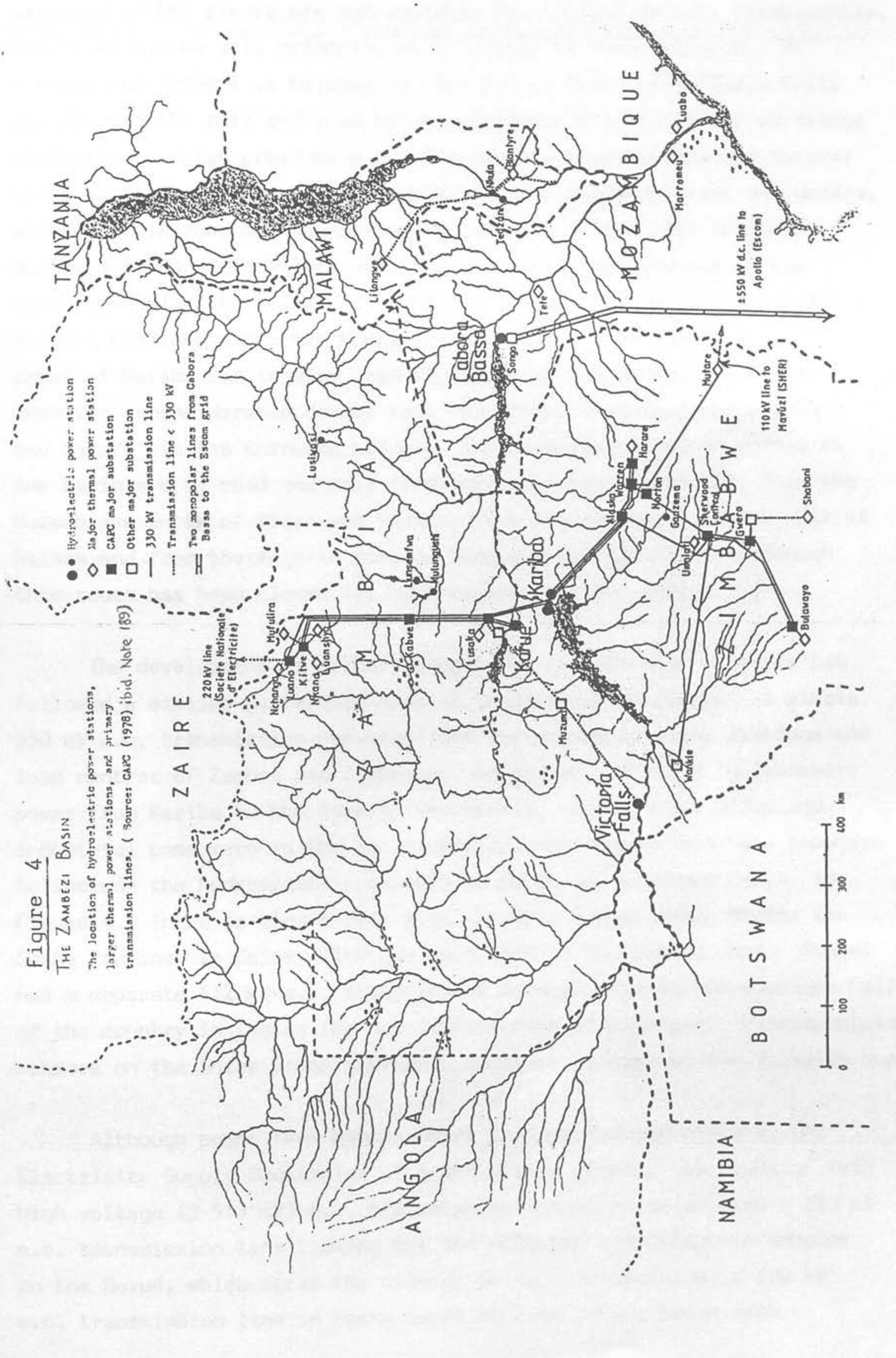


Figure 4

THE ZAMBEZI BASIN

The location of hydroelectric power stations, larger thermal power stations, and primary transmission lines. (Source: CAPC (1978) ibid. Note 89) railway which connects Malawi with the port of Beira. Road and rail links between other parts of the basin are poorly developed. The majority of the rivers are not suitable for navigation and, consequently, the river system acts primarily as a barrier to communication. At present the Zambezi is bridged in four places from the Victoria Falls downstream: the rail and road bridge at Victoria Falls; the road bridge at Chirundu, which provides a shorter route between Lusaka and Harare; the road bridge at Tete which provides a link between Malawi and Harare, although this road has been unusable for much of the last ten years during periods of conflict; and the rail bridge at Mutarara on the line from Malawi to Beira. In addition, a new road bridge is currently nearing completion further downstream, at Caia. The road across the crest of Kariba Dam is also used for crossing the river although it involves a considerable detour from the direct route between Lusaka and Harare via the Chirundu bridge. The principal means of access to the basin are by road and rail from various ports in the RSA, from the Mozambican ports of Beira and Maputo, from the Tanzanian port of Dar es Salaam and from the Angolan port of Benguela through Zaire, although this route has been closed for much of the last ten years.

The development of primary electrical transmission networks has followed a similar pattern to that of transportation routes. A single 330 kV a.c. transmission network links the principal power stations and load centres of Zambia and Zimbabwe. Developed initially to transport power from Kariba to the Zambian Copperbelt, and to other urban and industrial consumers in the two countries, the network has been expanded to include the hydroelectric schemes at Kafue and Victoria Falls, see Figure 4. There is also a link with the grid system which serves the Shaba Province in Zaire, although this link is now rarely used. Malawi has a separate 132 kV a.c. transmission network serving the southern half of the country including the new capital city of Lilongwe. Hydroelectric schemes on the Shire River provide a substantial part of the Malawian supply.

Although power from Cabora Bassa is supplied primarily to the Electricity Supply Commission of South Africa (Escom), by means of twin high voltage (± 533 kV) d.c. transmission lines, there is also a 220 kV a.c. transmission line linking the dam with the hydroelectric schemes on the Revué, which serve the city of Beira. In addition, a 220 kV a.c. transmission line is being built to link Cabora Bassa with various towns in northern Mozambique.

The economy of Mozambique

Accurate and up-to-date statistics on the economy of Mozambique are not readily available; the Government does not publish statistics on a regular basis and Mozambique is not a member of the IMF. The World Bank (1981), however, included the following statistics for 1979 in its report on world development:

Area: 783×10^3 km²;
Population: 10.2×10^6 (life expectancy: 47 years);
GDP: US \$ 2.36×10^9 (approximately \$250 per head of population);
Distribution of production: 44% agriculture, 16% industry (9% manufacturing), 40% services;
Mean annual growth in GDP: 1960 - 70, +4.6%,
1970 - 79, -2.9%;
Trade: no statistics given;
Mean annual growth in trade 1970 - 79: Exports, -16.6%
Imports, -14.4%

According to the World Bank's statistics, the country's GDP per head of population placed it twentieth in rank of the world's poorest countries; the large annual drop in production form 1970 to 1979 was only exceeded by one country in the world (Angola), and the dramatic decline in trade, both exports and imports, was worse than that of any other country. It is not known how these figures were obtained or how accurate they are. The population figure is almost certainly too low as, according the preliminary results of the First National Census, the population of Mozambique, in 1980, was 12.1 million[5]. Nevertheless, the overall picture arising from these statistics, of a relatively poor economy which has suffered considerable disruption during the last decade, is valid.

Two factors, in particular, have had considerable influence over the development of Mozambique's economy: its geographical location and its colonial history. Mozambique lies along the east coast of Africa, between latitudes 10° and 27° south, and has a coast line of over 2000 km.

During its early colonial history Portuguese influence did not stretch far beyond the immediate vicinity of a number of important ports. As Portuguese influence increased in the second half of the nineteenth century, the economy of the southern part of the country became shaped to the needs of South Africa, in particular, in the supply of migrant labour for the mines. The economic character of the centre and north of the country has been largely determined by chartered land companies, based on foreign capital, to which Portugal had granted access to the region's economic resources and had delegated administrative responsibility. Certain ports retained their importance being developed for the benefit of South Africa as well as Mozambique's land-locked neighbours. Transportation and labour supply subsequently retained their importance in the national economy as indicated by the high proportion of the GDP attributed to services in the 1979 statistics.

When the land companies were displaced by direct administration, in the 1930s, the Portuguese authorities began to exert a more direct influence over the economy of Mozambique. The colony came to be regarded as an important source of raw materials for Portuguese industries in Europe as well as providing vast areas of potential agricultural land on which to settle umemployed European Portuguese. Thus, no attempt was made to create a balanced or self-sufficient economy in Mozambique. Historical factors, such as these, in combination with certain geographical features hinder Mozambique's development as an integrated economic unit. In particular, the dissection of the land by numerous east-flowing rivers and the location of the capital city, Maputo (formerly Lourenço Marques), at the extreme south of the country, have helped to create enormous economic, political and administrative problems for the post-independence government. Communications within the country are extremely poor with few of its principal centres of production linked directly by rail or tarred road. The construction of a trunk road running the full length of the country was begun before independence and has been continued as a priority project since but, because of the technical difficulties involved, including that of bridging the Zambezi and many smaller rivers, it is still not complete.

Agriculture is of primary importance in both the monetary and non-monetary sectors of Mozambique's economy. The Portuguese authorities placed considerable emphasis on the expansion of commercial agriculture, particularly in the last decades of their administration. Their objectives were to provide raw materials for Portuguese industry (notably cotton), to produce goods for export, or for import substitution in Portugal, (such as cashew nuts, sugar, tea and copra) and to establish the conditions for a market economy in order to attract European settlers and to increase the pressure on the African population to relinquish its subsistence economy and provide the labour sought by colonial enterprise. In order to achieve these objectives, large plantations, estates and irrigated settlement schemes were established. The importance of these centres of production has been recognised since independence although their control and ownership has now largely been taken over by the State or by co-operative groups. There has also been an attempt by the authorities to stimulate the subsistence sector through the formation of *aldeias comunais*.* It is beyond the scope of the present work to discuss in detail many important aspects of the development of Mozambique's agricultural economy. Further details may be obtained from references[6] regarding such questions as the social, political and environmental effects of colonial labour recruitment and forced cotton production; the role of agriculture during the struggle for independence; and the debate which has taken place since independence over the allocation of resources between large-scale, mechanized, state enterprises and small-scale, collective, rural development projects.

The following selected statistics provide an outline of the characteristics of commerical agricultural production in Mozambique since 1960. According to estimates provided in successive FAO Yearbooks, the Portuguese authorities during the 1960s classified only 3% of Mozambique's land area as arable and 0.3% as being under permanent crops against 58% pasture and 25% forest. Only a small proportion of the country was, therefore, under intensive cultivation. Nevertheless agricultural production provided the country's principal source of export earnings. Total exports for 1961 and 1968 were recorded as 2.7×10^6 contos and 4.5×10^6 contos respectively[7] (US \$ 95×10^6 and US \$ 155×10^6). In 1961, 77% of the total was provided by agricultural products 58% being provided from only four crops, cashew nuts, cotton, sugar and tea[8]. In 1968 these figures had fallen to 65%,

* Singular, *aldeia comunal*: communal village.

for the proportion of export earnings provided by all agricultural products, and 47% for the contribution from the four principal crops.

The importance of agricultural production to trade immediately following independence changed very little. Of the country's total export revenue of 4.4×10^6 contos (US \$ 170×10^6) recorded for 1976, 53% was provided by the four agricultural crops listed above[9]. Official projections, at that time, of the expansion of Mozambique's exports indicate that the authorities foresaw the same four crops providing between 40% and 50% of export earnings throughout the following five years.

Dependence on a limited range of agricultural products to provide such a large proportion of export revenue renders the national economy exceedingly vulnerable both to changes in output resulting from the effects of climatic changes (or attack by pests and disease) and to changes in the prices paid in world commodity markets over which countries such a Mozambique have little influence.

Statistics about the extent of, and output from, subsistence agriculture are, at best, only approximate but the following figures[10] give some indication of the contrast between the commercial and subsistence sectors in Mozambique in 1967. The total area covered by each was approximately the same, 22000 km², but whereas the subsistence sector comprised 1.5×10^6 units, with a mean area 1.4 ha, in the commercial sector there were only 4×10^3 units, with a mean area of cultivation of 520 ha. In the lower Zambezi basin the difference was even greater with commercial holdings averaging between 1000 and 1500 ha.

Wuyts (1978) undertook a detailed study of the role of peasant production during the latter years of colonial rule. He concluded that, over the country as a whole, subsistence production accounted for 55% of agricultural output. Of the remaining 45%, which was sold commercially, one third was also derived from peasant production, one third was produced on plantations and the final third was produced by other farms and estates owned by Europeans. On this basis, 70% of all agricultural output derives from peasant production.

Both in terms of total agricultural output and in terms of commercial production, the central region of Mozambique, Manica/Sofala Tete and Zambézia (a large part of which lies in the Zambezi Basin), is of considerable national importance. According to Wyuts, commercial output from this region in 1967 accounted for 57% of the national total although Tete Province contributed less than 3%, to the region's agricultural revenue, the remainder being provided almost equally between the other two provinces. In Manica/Sofala and Zambézia the ratios between commercial output from peasant production and from plantation and other European-controlled production were amongst the lowest in the country, 10 to 20%, whereas in Tete the peasants provided about half the commercial agricultural production. Such figures indicate the commercial importance, in the late 1960s, of agricultural production in the plantations of the floodplain and coastal regions of the Zambezi basin. They also indicate the relatively underdeveloped state of agricultural production in Tete Province.

From general studies of agricultural potential, such as that of Gouveia (1969), based on investigations into physiography, climate, soils, natural vegetation, fauna and demography, the Zambezi basin provides the most diverse and some of the richest agricultural conditions of any region of similar size in Mozambique. Such studies support the widespread belief of previous Portuguese administrations as well as the casual observations of visitors to the region, including nineteenth century British explorers, that the Zambezi valley has a vast unexploited or underexploited agricultural potential. This belief had an important influence over the establishment of the MFPZ and over the type of project which it subsequently proposed. Recently it has prompted the renewed investigation of large-scale irrigation projects in the lower valley which is currently being carried out.

Output from the industrial sector of Mozambique's economy is small relative to that from agriculture. Nevertheless, the characteristics of established industrial production have an important influence over the future development of the national economy.

At the time of its independence, official statistics indicated that Mozambique had a relatively high level of industrial development compared to many other African countries. In 1973 the value of production from manufacturing industry placed it within the top eight most industrialized countries in Africa[11]. Furthermore, production was predominantly directed towards the domestic market with only about one third being exported. This pattern had been established only towards the end of the colonial era. According to Torp (1979), the structure of the Mozambican economy had changed from that at the end of last century when it had been dominated by non-Portuguese companies geared, almost exclusively, to exports. New industries had been gradually introduced to meet the needs of Portuguese settlers although it was not until about 1960, at the start of a rapid phase of industrial growth, that the export orientation was finally overtaken by the expanding production of domestic consumption goods. It is beyond the scope of this study to provide a detailed analysis of the various industrial sectors which were created but a general picture of the size and relative importance of the different sectors may be obtained from a study of employment statistics (for 1962, 1969 and 1973) and gross output statistics (for 1973) presented in Table 2. These figures indicate that agriculturally based industries (food, beverages, tobacco, textiles, leather goods) accounted for over half of the gross output from manufacturing. Nevertheless, a range of other industries was being created which, at first sight, appear to offer a good basis for balanced industrial development in the future. These include fertilizer production, cement, vehicle and machine assembly and repair, metal fabrications, furniture making and tyre manufacture.

Following independence the shortcomings of this industrial base became increasingly apparent. Apart from food, cotton and other agricultural processing units, industries are heavily concentrated around Maputo and, to a lesser extent, Beira. The resulting concentration of the skilled workforce, the relatively advanced infrastructure development of these regions, and the difficulties in transporting the final and intermediate products to other parts of the country provide major obstacles to achieving regionally balanced industrial production. Even within the present industrial zones, however, integration of the different production units is poor. Many are totally dependent on the import of certain key inputs or spare parts for machinery with the result that government controls on foreign exchange, in operation

Table 2: Published statistics of Mozambique's industrial sector

ISIC Category	Brief Description	Employees (Numbers)				Gross Output 1973		Mean Capital Investment per employee (Esc. x 10^3)	
		1962	1969	1973	(% of total manufacturing)	Esc. x 10^6	(% of total manufacturing)	1962	1969
3.1	Food, beverage, tobacco	21 171	29 499	45 751	(46)	6 821	(44)	104,5	154,1
3.2	Textiles, clothing, footwear	12 189	11 914	16 678	(17)	2 659	(17)	95,7	154,1
3.3	Wood, furniture	12 224	13 189	12 139	(12)	707	(5)	33,1	58,5
3.4	Paper, printing	1 518	2 246	3 809	(4)	587	(4)	67,6	152,9
3.5	Chemical industries	2 549	2 098	4 232	(4)	2 001	(13)	246,8	611,3
3.6	Pottery, glass, non-metallic	3 677	3 609	4 688	(5)	847	(5)	139,9	282,7
3.7	Metals		221	1 131	(1)	367	(2)		414,9
3.8	Metal fabrication, electrical, vehicular (inc. repair)	5 300	9 437	10 442	(10)	1 581	(10)	54, 4	110,3
3.9	Other	462	831	632	(1)	69		115,2	112,9

Table 2 cont.

ISIC Category	Brief Description	Employees (Numbers)			Gross Output 1973	Mean Capital Investment per employee (Esc. x 10^3)	
		1962	1969	1973	Esc. x 10^6	1962	1969
3	Total manufacturing	59 090	73 044	99 503	15 639	90,7	150,9
2	Mining and quarrying	N/A	N/A	6 529	275	N/A	N/A
4	Electricity, gas	N/A	N/A	2 795	682	N/A	N/A

Sources: Martins (1974) p142
Torp (1979) p15

N/A = Not available from these sources.

since independence, have frequently resulted in lost production.

The most traumatic effect on Mozambique's industry was, however, the departure of Portuguese personnel during the transition to independence. Within a very short period industries lost not only their managerial and technical staff but also many of their skilled workers. (In addition, before their departure, many adopted a policy of mismanagement or, in some cases, the deliberate removal and sabotage of capital equipment[12]). Serious inadequacies in Portugal's educational provision for African children left few Mozambicans equipped to fill the positions left vacant by the fleeing Portuguese.

The political and economic policies of the Mozambican Government

The Frelimo Party, which had its origins in 1962 in a broadly based amalgamation of three political groups enabling Mozambicans to unite in armed opposition to Portuguese colonialism has evolved into a vanguard party adopting the ideology and theories of scientific socialism[13]. The party continues to lay great emphasis on the unity of all Mozambicans, workers and peasants, whatever their race, culture or creed, and on the continuing revolutionary struggle against all forces of oppression and exploitation in whatever form they may appear. Such ideals are repeated frequently in major speeches. For example, in his Independence Day speech on 25 June 1980 President Samora Machel said:

> We are engaged in the struggle to build socialism because we know that socialism is synonymous with happiness, well-being, justice, progress and peace. We want to build socialism because we want to free outselves for ever from injustice, exploitation, hunger, lack of clothing, misery, illness and ignorance[14].

Faced with the enormous problems of underdevelopment which affect the bulk of the population Frelimo has imposed centralized control over the development of the economy in an attempt to ensure a just and efficient use of available resourses[15]. At the same time it has attempted to stimulate the creative initiative of the population through education and the spreading of co-operative ideals in order that the vast untapped human resources of the country might be developed[16]. The formation of local dynamising groups[17] during the period of transition to independence and the emphasis which has been placed on co-operative production and marketing are examples of practical attempts to increase popular participation. Nevertheless, because of the need to rebuild the disrupted economy, the Government has encouraged enterprises based on private and external capital to continue operating in Mozambique provided they do not violate Frelimo's economic and political policies. In practice, however, capitalist goals have often proved irreconcilable with these policies and state intervention has ensued.

In the short-term the economic objectives of the Government have been stated as follows:

> Let us reach 1990 with a developed industry, with primary industry in operation and with agriculture relatively mechanized. By 1990 the problems of food, clothing, shoes, unemployment, illiteracy, the endemic diseases which decimate our People, have to be resolved and conquered[18].

The application of these policies, particularly in the agricultural and industrial sectors, and their implications for the development of the Zambezi Valley are discussed below.

Mozambique's agricultural policies have been chosen to fulfil both political and economic objectives. Three major objectives, which are primarily economic, have been set out as follows: to produce sufficient food to feed the rural population and provide a surplus in order to supply urban areas with maize, groundnuts, rice, vegetables, fruit, meat and eggs; to provide raw materials for manufacturing industry, including oils, cashew nuts, textiles, meat and vegetable derivatives and fruit juices; and to provide export revenue[19]. The specific economic objectives defined for the period 1977 - 80 were: to guarantee the supply of the principal agricultural products in order to reduce imports; to improve the diet of the population (including greater crop diversity); and to give special attention to supplying food to urban areas; and to re-establish production at the highest pre-independence levels to provide both export revenue and the products necessary as inputs to established industrial units in the country[20]. As a first step in realizing these objectives the Government took over the farms abandoned by Portuguese settlers who had fled the country at the time of independence. The establishment of state farms was seen as the quickest way to re-establish output. At the same time it was hoped that, in future, these farms would become centres for research and places where training and education in agricultural techniques could take place.

The creation of state farms was also designed to serve the Government's political objectives, particularly in providing a base for the creation of an organized and politically educated rural proletariat. However, at present, state farms affect only a small proportion of the rural population the majority of whom remain as peasant producers. The Government's political policies for the subsistence sector envisage its transformation by collectivization and the formation of communal villages. Collectivization, it is believed, will lead to peasant control over production and, eventually, to the socialization of agriculture. It will also enable surpluses to be generated which can be invested in machinery. In the long-term, it is believed that this will lead to the 'industrialization' of rural areas through the formation of agro-industrial complexes which will reduce the differences between the rural and urban populations[21]. The strategy was summarized by Samora Machel as follows:

> Our agricultural development is founded on small and large projects, on small and large endeavours. Our development is based above all in the organization and mobilization of the peasants, in the correct organization and mobilization of the agricultural workers, in the development of their scientific understanding and skills, in their identification with the mentality of the working class[22].

In their practical application, Frelimo's economic and political policies in the agricultural sector have led to ambiguities and conflicts. To develop a rural working class the Government has sought rapid mechanization but, with the country's present lack of human skills and financial resources, this has involved heavy dependence on foreign capital and skills thus reducing the control which Mozambicans have over their economy. At the same time the authorities have had to direct their limited resources into selected projects which, of necessity, benefit only a small proportion of the population. Thus, new inequalities are created. The Government has attempted to reduce these problems through collectivization which prevents local inequalities and gives the rural population greater control over their means of production. Such a course, however, leads to very slow growth in agricultural output and so does little to reduce wider inequalities. Finally, conflicts exist in the allocation of resources between the three aspects of Frelimo's economic policy for agriculture: food production, supply of industrial inputs and production of export commodities.

With its present resources the Government can do little to resolve such conflicts. Its initial response has been to re-establish production as it was under Portuguese rule but under the control of new political and organizational structures designed to increase worker participation. In allocating money for new projects an attempt has been made to benefit all sectors - family units, collective units and mechanized state farms - although the large-scale, mechanized projects appear, up until now, to have received the major share. As with the previous Portuguese administration, lack of resources has not prevented the Government from authorizing a number of detailed surveys of the country's natural resources and agricultural potential. These have resulted in outline plans for a number of projects many of which are well beyond the country's present capabilities.

Torp (1979) has interpreted Frelimo's policies regarding industrial development as follows:

> In brief, FRELIMO's objectives in the industrial sector, during the first three years of independence, have been on the one hand to create the basis of socialist relations of production, directed by the state and led by the workers, and on the other hand to increase the production of consumption goods, means of production for the agricultural sector and export earnings. (p30)

Within the framework of these objectives the Government's initial aim has been to provide adequate food, clothing and housing for the people; the production of so-called 'basic needs'. Clearly, the achievement of this aim depends largely on successful agricultural development as indicated above. In the long-term, however, it is hoped that industry will make its own contribution to Mozambique's development, enabling a fairer distribution of resources through the implementation of industrial projects in such areas as the hitherto neglected region north of the Zambezi. In addition it is hoped that industrialization will transform the country's external trade, by making Mozambique more self-sufficient in consumer goods, and that it will bring revenue which will enable the Government to pay for new development projects.

As with agricultural policies, conflicts have arisen in their application as a direct result of the limited resources at the Government's disposal. One of the principal areas of debate has been how far the authorities should promote *grandes projectos* (large projects) which require large initial capital inputs and large numbers of foreign technicians as opposed to alternatives such as small industrial units, simple technologies and rural workshops. As far as one can tell at present, an attempt is being made to promote the two approaches simultaneously although, as with agriculture, the large projects appear to be receiving a larger share of the available resources.

Some of the industrial plans which have received the closest attention have been as follows: textile mills at various locations, including Manica, Mocuba, Namupla, Cuamba, Montepuez and Pemba; a paper mill near Chimoio; industries around Beira including heavy vehicles, pharmaceuticals, furniture and, possibly, steel production based on the iron ore deposits at Honda; petro-chemical industries, including fertilizer production from the natural gas field south of Beira; cement and other chemical industries at Nacala; light industries including shoes and clothes; and numerous processing units based on agriculture and fisheries. In addition, development of the coal at Moatize and the pegmatite minerals of Alto Molócuè, the smelting of aluminium at Caia, electrification of the railways and agro-industries assocaited with extensive irrigation developments, particularly in the Zambezi and Revué basins, have all been proposed[23]. The co-ordination of development between the SADCC countries may, in future, add a new factor in the formulation on industrialization policies in Mozambique.

As regards the present study, policy decisions, such as those described above for the agricultural and industrial sectors, will have a major influence over water resources development in the Zambezi valley. In particular, the extent to which large-scale irrigation is promoted will influence decisions concerning the operation of the Cabora Bassa Dam and the allocation of surface water resources. In addition the distribution and growth of heavy industry will be closely related to the supply of electrical energy and will, therefore, influence decisions concerning the design of Mozambique's electrical transmission networks and its future energy sources, including the proposed North Bank Power Station at Cabora Bassa.

International aspects of water resources engineering in the Zambezi basin

The political sub-division of the Zambezi basin, described above, leads to international problems in the planning and operation of all major river regulation projects. The Kariba Project lies on the stretch of river which forms the border between Zambia and Zimbabwe. Co-operation between the two Governments has been necessary for the operation of Kariba and will be necessary for any future hydroelectric project along that stretch of the Zambezi. At present Angola has no major river regulation works within its part of the catchment and, therefore, has very little direct influence over the hydrology of the Kariba Project although the operation of the dam has been made more difficult since Angola ceased to supply upstream hydrological information.

For Mozambique, by contrast, international problems concerning other basin states arise primarily from the upstream regulation of river flows. In particular, discharges from the Kariba Dam have a considerable influence over the inflows to Lake Cabora Bassa. Also, downstream of Cabora Bassa, Malawi and Zimbabwe have considerable influence over the discharges of two of the largest tributaries, the Shire and the Luenha/Mazoe. Within Mozambique this problem is not unique to the Zambezi basin. On the basis of information obtained from Serviços Hidráulicos (1972) over 30% of the area of Mozambique lies within international river basins whose major part is beyond the country's borders. Apart from the Zambezi, these basins include the Maputo, Incomati, Umbeluzi, Limpopo and Save which provide some of the country's most important urban and agricultural water supplies. Adding the Rovuma to this list, since its channel forms the border with Tanzania, although only 35% of its catchment is outside Mozambique, increases to approximately 45% the proportion of the country covered by basins in which Mozambique's activities are significantly influenced by international factors. Nevertheless, the former Portuguese administrators obtained no formal treaties with the authorities in neighbouring countries over the regulation of these basins. The only treaty which they concluded with reference to the Zambezi basin was one signed in 1881 with the United Kingdom which opened the Zambezi, the Shire and their tributaries to navigation under all flags[24]. More recently, Moreno (1967) noted that Portugal was seeking to establish agreements with upstream basin states with a view to improved utilization of the water of Mozambique's international basins. However, no formal agreements were reached.

The one notable attempt to obtain international agreement over the regulation of the Zambezi arose from a British initiative which resulted in a conference, in 1950, between technical representatives of the principal basin states, to discuss the implications of the proposed Kariba Dam (see Chapter 2). Suspicious of British intentions, Portugal's politicians appear to have resisted efforts to enter diplomatic, rather than simply technical, discussions and to have rejected the idea of establishing some form of Zambezi River Authority. Once the Kariba Project had been implemented, the former colonial authorities in Zimbabwe and Zambia also lost interest in wider international co-operation although a joint power company (later to become the Central African Power Corporation) was established between them to operate the Kariba Dam and the high voltage transmission lines to the load centres in the two countries. Co-operation between these two countries in the generation and supply of electrical power continued throughout the years preceding Zimbabwe's independence despite political and practical difficulties, which arose from the imposition of international economic sanctions on the white Rhodesian government, and the increasing armed conflict occuring within and around that country. Since Zimbabwe's indepedence considerable interest has been shown in further co-operation between the two countries on new hydroelectric projects which have been proposed on the Zambezi along their common border. But, so far, no attempt has been made to involve Angola and Mozambique in the planning of these or other projects. To a large extent this is unnecessary as far as Mozambique is concerned since additional upstream regulation at new hydroelectric projects would probably bring net benefits for both power production and flood control at Cabora Bassa. Increased evaporation losses from new storage reservoirs would not, at present, be critical to Cabora Bassa's operation without a massive increase in water consumption upstream. This could only arise in the unlikely event of Zambia or Zimbabwe undertaking vast irrigation projects or effecting large inter-basin water transfers. Nevertheless, Cabora Bassa's output cannot be optimized without constant exchange of data and operating information with projects upstream.

The operation of the Cabora Bassa Project introduces other problems of an international nature amongst which the agreement to sell electrical energy to the RSA is of particular significance to the present study. The implications of this agreement are discussed in detail in Chapter 4. The Cabora Bassa power agreement was only one aspect of the heavy dependence of the Mozambican economy on the RSA at the time of independence. Other aspects included transportation and trading links as well as labour migration to South African mines. With the Cabora Bassa Project, as with many other aspects of their dependence on the RSA, the authorities in Mozambique have very little ability to influence the relationship. Attempts by Mozambique to sever its links with the RSA would cause considerably more damage to the economy of Mozambique than to that of South Africa. As Olivier (1975) argued in reference to Cabora Bassa:

> The dam will not be used as a weapon against South Africa in the same way that the Arabs have used their oil. Who else would buy the power? The choice of market is limited and the income is vital for the future development of the project. (p143)

He might also have added that, whereas the electricity grid of the Electricity Supply Commission of the RSA (Escom) is now so large that loss of supply from Cabora Bassa would cause only minor disruption, the supply to Mozambique's capital, Maputo, a large proportion of which, 'comes from Cabora Bassa' via the Escom grid, would be severely disrupted if the RSA retaliated by cutting that link.

For a number of years certain prominent white South Africans have emphasized the advantages to the apartheid regime of increasing the economic dependence of neighbouring states on the RSA. The established system of rail and road transport already serves that end. The creation of an inter-connected electricity supply system in southern Africa would increase dependence. Norman (1969) predicted that:

> the 1980s may well see a completely inter-connected system in southern Africa using the latest technology regarding high voltage a.c. and d.c. links and large conventional, nuclear and hydro-electric power stations. (p19)

Olivier became a leading advocate of such a system which would be capable of bringing cheap hydroelectric power from as far away as the Inga Project, in Zaire, to the power-hungry mines and industry of the RSA. In an address delivered in 1973 he demonstrated, convincingly, the benefits to the RSA of such an arrangement but was less convincing in his analysis of the benefits to the countries in which the projects would be sited despite assuring his audience that:

> history has shown how durable are the ties between nations which are connected by an electrical transmission grid which could be used to export and import power as may be required thus optimizing the economic benefits for all parties.

Olivier entitled subsequent elaborations of these proposals, whose primary effect would be to strengthen the apartheid system, as 'engineering for peace'[25] and 'engineering for detente'[26].

In an attempt to weaken their dependence on the RSA, by greater interdependence amongst themselves, the Heads of State of the nine 'front line' states, Angola, Botswana, Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia and Zimbabwe, together with representatives from Namibia, met in Lusaka in April 1980 and committed themselves to co-ordinate their development planning as proposed at the first SADCC Conference in Arusha in July 1979. Initially, priority was given to seeking international financial aid for selected projects which would help to free the countries from their dependence on the transport system of the RSA. However, it is intended that greater co-operation will in future be achieved in all aspects of their economic activity. SADCC may, therefore, among other things provide a forum in which problems associated with the management of international basins, such as that of the Zambezi, could be resolved and in which regional co-operation in planning the supply and consumption of electrical energy could be achieved.

Finally, Portugal's involvement in supervising the repayment of the capital invested in the Cabora Bassa Project provides an additional international dimension to the regulation of the Zambezi. Portugal acts through the agency of Hidroeléctrica de Cahora Bassa (HCB), a Portuguese registered company responsible not only for managing the financial repayments but also, through a lease arrangement, for the entire physical operation and maintenance of the project. HCB, therefore, has an important influence over the benefits which Mozambique might obtain from the project. The fact that the company is based in Lisbon and that it is in Lisbon that all decisions concerning the project are taken, including day-to-day decisions concerning its hydrological operation, is a matter of concern in Mozambique:

> We do not accept that decisions concerning Mozambique should be taken outside Mozambique[27].

Administrative constraints on water resources planning in the lower Zambezi

As an administrative unit the Zambezi valley in Mozambique has had a varied history. By the mid-fifteenth century, before the arrival of Portuguese settlers, the powerful Mutapa empire had extended its authority over a large area including the whole of the Zambezi valley south of the river as far upstream as Kariba Gorge. As the Mutapa's authority declined Portuguese settlers were gradually able to assume jurisdiction over tracts of land and to control trading fairs. Since their numbers were relatively small and since many subsequently inter-married and rejected Portuguese authority, setting up African-style kingdoms, the Portuguese State was not able to fully assert its dominance in the region until the early twentieth century. Nevertheless, Portugal regarded the lower Zambezi as lying under its fiscal administration. During the seventeenth century it was administered as a single region under the supervision of Goa. Thereafter, it was placed under the supervision of Ilha de Moçambique but with a considerable degree of autonomy. In the nineteenth century various attempts were made to sub-divide the region including the separation from it of the area lying in present-day Zambézia and, at one time, the granting of separate status to the region around Zumbo in an attempt to extend Portuguese claims of jurisdiction upstream of the Luangwa confluence. By the beginning of the twentieth century the present administrative divisions of the lower Zambezi into Provinces had been more-or-less determined. With the establishment of the Missão de Fomento e Povoamento do Zambeze (MFPZ) by the Portuguese authorities, in 1956, the lower Zambezi basin was once more treated as a single unit although the MFPZ's terms of reference were, at that stage, limited to the work of investigation and planning. Later the MFPZ was reformed and given executive authority over the implementation of the Cabora Bassa Project and its ancillary works, including the resettlement of those displaced by the reservoir. Following independence, the Mozambican Government disbanded this body and assumed the responsibility for planning in the Zambezi valley within the national planning agency. The activities of HCB, formed to operate the Cabora Bassa Project, were placed under the scrutiny of other central government agencies.

In its early stages, parallels were drawn between the MFPZ and the Tennessee Valley Authority (TVA) in the USA. From comparison of the details of the TVA, discussed in Chapter 1, with the description of the MFPZ, given in Chapter 2, it is apparent that the two cases were very different. The MFPZ operated in only a small part (11%) of the Zambezi basin; this region lacks many of the physical and economic features which contributed to the TVA's success; politically, there were considerable differences between the TVA's ideals of democracy and the plans of the MFPZ which were designed to support a colonial economy, and to benefit the mainly white 'civilized' settlers who would be introduced to the region rather than to benefit the existing population; and, finally, the MFPZ had no guaranteed source of finance nor did it have executive authority to implement its proposals. Only in its adoption of a unified approach to natural resources development was the MFPZ similar to the TVA. The MFPZ, in fact, showed closer similarity to the river basin planning commissions, also referred to in Chapter 1, which were set up in the USA to produce co-ordinated development plans for such basins as the Columbia than to the TVA. Like these commissions, once the plans were produced it rested with central government or private enterprise to determine whether a particular project would be implemented. On the lower Zambezi one project took precedence over all others - the Cabora Bassa Dam. Politicians in Lisbon finally agreed to give this project their support but, in order to attract Western and South African finance, the details of the original plans were modified in order to increase economic returns. The result was that the final installation was less adaptable to the multiple purpose operation envisaged by Portuguese engineers and more suitable to meet the single purpose objective of supplying power to the RSA.

The idea of river basin planning and administration has not been widely canvassed in Mozambique since independence. A National Water Plan[28] prepared for the period 1977-2000 undertook analyses of irrigation, flood control and hydroelectricity over the country as a whole without reference to the integrated development of separate river basins. Planning and administration appear to be undertaken at a national level or within established political regions. However, the establishment of a State Secretariat for the Planning of Accelerated Development of Irrigation in the Limpopo and Incomati Valleys[29], by Presidential Decree in October 1979, indicated that, in this case, the Government recognized the importance of adopting a new, geographically defined, region. Nevertheless, in rural development, the authorities have adopted a 'vertical' approach to planning as regards their *aldeias comunais* programme. The programme, planned and co-ordinated from Maputo, is an attempt to achieve homogeneous development in which no area is given priority. This approach is criticized by Friedmann (1980) mainly on the grounds of Mozambique's shortage of resources and skilled personnel. He proposed, instead, a decentralized, territorial approach to rural development with resources concentrated in key centres. However, he did not consider river basins as possible planning or administrative regions.

Effective management of the resources of Mozambique is at present restricted by the lack of effective co-ordination between different government agencies. The national planning agency co-ordinates matters related to the planning of the national economy but detailed planning of individual projects is undertaken by separate government agencies. In the case of the lower Zambezi the lack of a co-ordinating body, for such matters as physical planning and project operation, was seen as an obstacle to co-ordinated development at the time of the writer's visit to Mozambique in 1979/80. At that time, HCB's operation of the Cabora Bassa Dam was monitored primarily by the Direcção Nacional de Energia, which was concerned with the project's power output and with energy planning in the region. The Direcção Nacional de Águas (DNA)* was

* National Water Directorate

engaged in studies of flood alleviation and flood warning downstream of the dam, and with the exchange of hydrological information with HCB. The Ministery of Agriculture was involved in the planning of agricultural production and, in particular, in studying proposals for large-scale irrigation projects on the alluvial plain. Other government agencies were concerned with fisheries production and possible weed infestation in Cabora Bassa Lake. Finally, the managers of the sugar estates at Marromeu and Luabo, the ferry operators and bridge builders at Caia and the authorities in the municipalities along the river were all concerned with rapid changes in river level arising from changes in the rates of discharge from the dam. Since no agency was in a position to fully assimilate and respond to the often conflicting demands of the parties involved (although HCB had apparently attempted to assume that position), it was not possible either to achieve efficient management of the region or to ensure that HCB would not use the conflicts and ambiguities to its own advantage.

In studying water resources planning it is particularly important to consider the time horizon in which different agencies are working. For its first years of independence the Mozambican authorities have had to concentrate on solving many immediate problems not least of which being those associated with ensuring national security. In such circumstances long-term questions, including the potential problems of resource depletion and environmental degradation, could not be given adequate consideration. Even the preparation of national economic five-year plans has presented difficulties.

The Mozambican authorities face particular constraints on their ability to choose the form of water resources planning and administration which they will adopt and the relative priorities which they will place on long-term and short-term considerations. These constraints, as discussed below, arise from the lack of adequate data and information and the lack of qualified personnel.

Prior to 1950, the Portuguese administrators did relatively little to obtain hydrological, meteorological and topographical data and other information relevant to the development of natural resources over large areas of Mozambique. Thereafter, the establishment of recording stations was given higher priority with the result that the network of stations were relatively well developed by the time of independence[30]. Nevertheless, many of the stations had such short series records that they were of little practical value. The need for, and cost of, establishing and maintaining an adequate network of hydrological stations in respect of the operation of the Kariba Project was considered in the discussion of the paper by Reeve and Edmonds (1965). Such a system is necessary for the purposes of both planning and operating water resources projects. In the lower Zambezi basin many hydrological stations fell into disuse during the armed conflict preceding independence and others were subsequently neglected because the departure of Portuguese personnel left few qualified hydrometrists in the country.

Even the existence of a large number of records is of limited value without detailed studies of their accuracy and validity, particularly in the many instances in which records exist only for short or intermittent periods. For the lower Zambezi, studies of statistical data were included in the investigations of the MFPZ and published in the *Plano Geral*. Similar *Planos Gerais* were also prepared for other river basins in Mozambique. Because of their present importance as the primary sources of information for water resources planning careful consideration of the quality of these reports is desirable. Some reservations about the technical quality of parts of the MFPZ's work and about the applicability of its proposals to the present situation in Mozambique are expressed in this thesis. Such conclusions serve to indicate the extent of the problem, now facing Mozambique, in obtaining reliable data and information and in the interpretation of this information for water resources planning.

The preparation for, and implementation and operation of, large-scale water resources projects or integrated river basin development plans demands considerable technical and administrative resources, including large numbers of suitably qualified personnel. The lack of qualified personnel at all levels in Mozambique, following the exodus of Portuguese nationals at independence, has been identified as one of the country's most acute problems. Portuguese personnel had filled not only the top administrative and technical positions in Mozambique but also the majority of the positions requiring artisan or clerical skills. This, together with the lack of educational opportunities available to the majority of the black population, prevented many Mozambicans from gaining the necessary education and training to take over these positions*. The implications in terms of water management policies are considerable. On the one hand, strong emphasis has been placed on the training of Mozambicans (see the conditions stipulated in Appendix 5 for the North Bank Power Station). On the other hand, in the short-term, attempts are being made to limit the demand for qualified Mozambicans by using foreign advisors and consultants. As a result increasing emphasis is being placed on large single-purpose projects which can be built with foreign technicians and operated with small numbers of highly specialized personnel. The impossibility of providing a sufficient number of qualified Mozambicans to staff an integrated river basin development programme may be seen from a study of the large number of staff employed by the MPFZ. In 1968 the agency, as well as making considerable use of the consultants Hidrotéchnica Portuguesa, employed its own technical staff of 115 of whom 32 were graduates[31]. Nevertheless, even the MPFZ, in its early years, had had problems obtaining suitably qualified staff. Even in 1958, after publication of *Relatório Preliminar*, only about one half of the higher technical posts were filled. In addition, of the six hydrometrists then employed only one had previous experience of the work, whilst none of the engineers had practical experience in hydrology[32].

Inadequate information and data together with shortages of skilled personnel make it extremely difficult for the authorities in Mozambique to utilize the techniques of mathematical modelling and systems analysis, which are currently being applied elsewhere to improve efficiency in water resource planning and the operation of multiple purpose reservoir projects.

Outline of the thesis

The literature survey of Chapter 1 gives some indication of how broad a field of study water resources engineering has become. Inevitably the scope of the present thesis has had to be restricted although in the initial investigations material from a wide variety of discipline sources was consulted in order to identify the more important factors which govern

* Subjective estimates of the number of Mozambican graduate engineers, of all types, remaining in the country after independence suggest that the total may have been no more than twenty.

the alternatives available to Mozambique in the management of the lower Zambezi. The principal purpose of the thesis has not been to consider whether the Cabora Bassa Dam should have been built nor to undertake a definitive post-audit of its costs and benefits, for which there is at present too little information available, but to consider the implications for Mozambique of the operation of the project as it now stands, and, further, to consider the possible implications of attempting to modify its operation or to undertake further projects in the valley.

It is clear that the operation of the Cabora Bassa Dam poses many problems for the Mozambican authorities. As Leonard (1974) predicted following the coup in Lisbon which preceded Mozambique's independence:

> Cabora Bassa ... may be an important resource for liberated Mozambique, but it is one that poses problems and challenges and it cannot be viewed simply as an intrinsic asset. (p41)

More recently in a journalistic account of the project by Gunnell (1980) the implication that the Cabora Bassa Project is, at present, more of a liability than an asset was conveyed in the blunt question of her title: 'When will Cabora Bassa benefit Mozambique?'

In order to achieve a more objective analysis it has been necessary to consider in detail certain technical aspects of the project's operation and to evaluate its social and environmental effects. These questions form the basis of separate chapters of the thesis. Questions related to the political and administrative aspects of water resources engineering in the lower Zambezi, discussed above, are not included in separate chapters but are considered throughout the thesis wherever relevant. In addition, discussion of these aspects is drawn together in the Summary and Conclusions. Throughout the thesis particular attention is paid to the possible implications of a north bank power station, at Cabora Bassa, in view of recent indications that the authorities in Mozambique intend to proceed with such a project.

Chapter 1 of the thesis provides a broad review of the literature on water resources engineering. Special attention is paid to studies of the TVA and to relevant case studies from around the world and, in particular, from sub-Saharan Africa.

Much of Chapter 2 is devoted to discussion of the historical background of the Cabora Bassa Project together with that of other water resources developments both in the lower Zambezi and further upstream. In addition, the chapter provides an introduction to the more important technical, social, political, economic and environmental characteristics of these developments.

Chapter 3 is a detailed discussion of the hydrology of the Zambezi and the operation of the Cabora Bassa Dam. The results from previous hydrological studies and the quality of available hydrological data are examined. Results from some original hydrological calculations are also included. The principal objectives are to identify conflicts and trade-offs which would result from operation of the Cabora Bassa Dam as a multiple purpose project, to examine the range of possible operating alternatives available to the authorities under different assumptions about the physical and operational constraints on the reservoir system, and to determine the sensitivity of predicted results to hydrological variations or to errors arising from the inadequacy of the original data.

Chapter 4 is an examination of the role of mining and industry in plans for the economic development of the Zambezi valley and of the influence of river regulation on these proposals. Particular attention is paid to the pattern of electrical power consumption in Mozambique, in the RSA and in other neighbouring countries. This is related to present arrangements for the financing of the project, including the contractual agreement to sell power to the RSA. The implications for the hydraulic operation of Cabora Bassa Dam of the present power contract, together with the economic and operational implications of possible changes in the arrangements for power generation and supply are also considered.

Chapter 5 is a broad review of the available information on soil erosion, sediment transport and reservoir siltation in the Zambezi basin. Comparisons are made between estimates of the siltation rates for Lakes Kariba and Cabora Bassa and predictions are made as to how soon, and in what way, siltation in Lake Cabora Bassa will affect the project's operation. In addition, the influence of Cabora Bassa Dam on sediment transport downstream and its possible effect on floodplain agriculture and river navigation are discussed. Original results obtained from the analysis of a limited number of sediment samples are incorporated in this part of study.

Chapter 6 is an investigation of the social and environmental effects of the Cabora Bassa Project using the results of a limited number of direct investigations which have been published and supported by comparisons with observations recorded from the effects of other projects, including Kariba. Here the principal objectives are to examine the changes which might result from adopting different operating procedures for the project, to predict the impact of any new projects which might be undertaken and to identify ways in which harmful effects resulting from the existing project, or from future projects, might be reduced.

Principal Sources

The broad scope of the thesis, mentioned above, has required that material be drawn from a wide variety of sources. It is not possible to review all of these in detail in this introduction but the prinicpal ones are discussed below. Other material is referred to in the Notes and References in the text.

Sherlock (1963) has provided a short bibliography of historical and non-technical references for the Zambezi up to the time of construction of the Kariba Dam. This proved useful in the preparation of Chapter 2 as few other researchers have treated the basin as a whole. Material has, however, been drawn from geographical and historical studies of separate basin states.

Amongst general works on Mozambique that of the Centre of African Studies, of the University of Edinburgh, (1978) is of particular value comprising, as it does, papers on the colonial history of Mozambique and on its post-independence economic and political development. An extensive bibliography, prepared by Chris Allen, of publications in languages other than Portuguese for the period since 1920 is also included.

The pre-independence history of Mozambique has been recorded in various English language publications including those of Duffy (1961 and 1962), Chilcote (1967), Henriksen (1978), and Newitt (1978 and 1981). The part of the Zambezi basin lying in present-day Mozambique is an area to which particular attention has been paid because of the important role of the *prazos* and, later, the plantation companies in its development. The following works were of value in the preparation of the material for Chapter 2: Head (1978), Isaacman (1972 and 1976), Ishemo (1978), Newitt (1969 and 1973) and Vail and White (1980).

The most significant study of the Cabora Bassa Project published to date is that of Middlemas (1975). As a source of factual information and as an account of the sequence of events leading to the dam's construction this work has proved invaluable for the present study. As a historical work its principal importance lies in Middlemas's ability to draw on the texts of numerous personal interviews which he undertook with the main participants although this has led to strong emphasis being placed on individual, subjective interpretations of events. His analysis of the personal and political factors which shaped the construction consortium provides a case study of particular interest to students of large international civil engineering construction projects. Middlemas does not, however, undertake a detailed discussion of the costs and benefits of the project nor does he foresee many of the problems of the project's operation posed for the new Government of Mozambique following independence.

Possibly the broadest analysis which has been attempted of the costs and benefits of the project is that contained in a short pre-impoundent study by Hall and Davies (1974). Being written by natural scientists, the paper places considerable emphasis on predictions about the environmental consequences of the dam. Possible social and economic issues are also referred to but political questions are largely neglected. Furthermore, the paper contains no detailed discussion of the technical factors which govern the project's operation.

The majority of technical and academic publications which refer to the Cabora Bassa Dam fall into one of two categories: descriptions of the technical features of the project, contained in technical journals or news magazines, and evaluations of the political aspects of the initial decision to build the dam. The former category will not be discussed here since none of the references contain original material or analyses: they are derived from a number of official pamphlets based on the technical reports described below. The latter category includes contributions by a number of prominent political scientists. The following, albeit written prior to Mozambique's gaining independence, are of particular interest: Davidson (1972), Grohs (1974), Henderson (1972), Radman (1974 a and b) and Programme to Combat Racism (1971).

The three multi-volumed reports prepared by the MFPZ, *Relatório Preliminar, Esquema Geral* and *Plano Geral*, of which details are given in Bibliography 1, together with supplementary reports undertaken for the MFPZ/GPZ, have provided much of the technical material for this study. For its sheer bulk the information contained in these reports is impressive although closer study reveals appreciable duplication and, in some instances, significant errors and omissions. Additional details about the technical aspects of the project are provided in various reports published by the Labatório Nacional de Engenharia Civil, in Lisbon, and in various papers published in the Portuguese journals *Electricidade* and *Fomento*. These journals also contain a number of papers which elaborate aspects of Portugal's colonial development policies. All the foregoing Portuguese reports and papers were written by technical advisors or administrators in the direct employ of the Portuguese authorities.

Very little independent research has been undertaken in Mozambique either before or after independence. Apart from the work of Middlemas the only pre-independence academic studies related to the Cabora Bassa Project, were a small number of anthropological and scientific investigations of the impact of the project. Even these, however, were commissioned by the MFPZ/GPZ and undertaken by staff of the university in Lourenço Marques. (For further details see Chapters 5 and 6). The writer knows of no academic study of the project, apart from the present work, which has been undertaken since independence.

Reference was made at the start of this introduction to a number of official technical reports published since work on this thesis commenced. The reports of the consulting engineers Messrs Rendel, Palmer and Tritton and of *Direcção Nacional de Águas* are referred to extensively in Chapter 3 but it has not been possible for the writer to consult some of the other consultants' reports. In most cases, however, where access to the documents was not possible, an outline of the conclusions reached has been obtained. The reports of SWECO were, unfortunately, only seen by the writer when he was completing the final draft of his thesis and it has, therefore, only been possible to make limited reference to them. These reports deserve credit as the first published studies to investigate the relationship between hydrological operation and environmental effects downstream and the first post-independence studies of potential markets for Cabora Bassa's electrical energy. In a number of places the SWECO reports have reached similar conclusions to those reached in this thesis. The fact that they were commissioned as part of the feasibility study for the proposed North Bank Power Station gives them particular relevance.

C H A P T E R 1

GENERAL LITERATURE SURVEY

The study of water resources engineering

Over the last fifty years the regulation of rivers and the utilization of water resources have become subjects of study for workers from increasingly diverse disciplines. This reflects the growing awareness amongst academics, and, to a lesser extent, planners and engineers, of the complex interdependence between technical, political, social, economic and environmental factors in the implementation of water resources projects. The quantity and breadth of published material now available prevents an exhaustive review of this literature from being undertaken in a work such as this. Nevertheless, a careful selection of the more important publications which were consulted whilst preparing this thesis, and which provided some of the concepts and ideas on which the research was based, are reviewed below.

In addition to the references provided in the bibliographies of many of the works cited below, the following bibliographic works have proved useful sources for a broad range of water resource development publications: Giefer (1976) covers many technical and non-technical aspects of water management using literature predominantly from the USA; International Commission on Irrigation and Drainage (1974) includes a wider range of sources although the subjects covered are more restricted; Hamilton (1966) concentrates on references of a socio-economic nature published between 1955 and 1956 in the USA; whilst Pickford (1977), focusing on developing countries, is concerned primarily with small scale water supply and sanitation works.

In considering water resources engineering it is useful to contrast two distinct approaches although, in reality, these form the opposite extremes of a continuous spectrum of possibilities. The first, which characterises almost all the water resources work undertaken before the present century, and which arises from consideration of a fairly limited set of technical and economic objectives, is the single project approach. Each project, whether a reservoir, water wheel, irrigation diversion or navigation canal, is designed to fulfil a single specific purpose, its 'economic' justification being derived from fulfilling that purpose and the technical details of its design being chosen in order to meet that objective. The majority of the old dams described by Smith (1972) fall within this category as do many of the ancient irrigation schemes and the innumerable small-scale works which have been built throughout the world for power, irrigation or water supply. Nevertheless, in certain cases, although projects have been planned singly, the subsequent interaction of separate projects has resulted in the creation of a complex interdependent system of water regulating works. Such a system may appear, in practice, to be similar to that which would result from the opposite planning approach, referred to as 'river basin planning' (also, as 'integrated' or 'comprehensive' river basin planning), which arises from a geographical or ecological view of development. In this approach the boundaries of the catchment area of a river basin are selected as the most logical limits for a coherent planning unit. The choice is made not only for technical reasons (the inevitable interdependence of all activities influencing or influenced by a single river system) but also for social, political and environmental reasons. Thus, project planners, although being responsible for achieving specific objectives of a hydraulic nature, seek, primarily, to co-ordinate water resources development with the whole economic and physical planning of the resources of the river basin including agriculture, forestry, industry, mining, navigation and fisheries, as well as with various social and political objectives. The theory of river basin planning received its most broad and vigorous trial some fifty years ago when, in 1933, the Tenessee Valley Authority (TVA) was established in the USA. (Details of the TVA and a discussion of its relevance to the present study are contained in a separate section below).

History provides examples of ancient water-based civilizations in many parts of the world in which the social and environmental effects of water resources engineering were of considerable importance. This was particularly true for those regions in which, without irrigation, permanent cultivation would have been impossible. (Bennett (1974) provides a penetrating discussion of the role of water regulation in various civilizations together with a useful review of the relevant literature). Nevertheless, the dramatic increase which has taken place in the present century in the number and the scale of river regulation works has strengthened public awareness of the social and environmental significance of water resources engineering and has awakened concern over their possible harmful effects. The formulation of the concept of river basin planning was, in part, a result of this concern.

The large man-made lakes which have been created in many parts of Africa since the 1950s as well as similar projects in other parts of the world provide a dramatic illustration of the vastly increasing power which technology now provides for influencing the physical environment, and human society, through the regulation of surface water resources.

There are very few published texts or symposia proceedings which treat the planning for, and impact of, water resources development in a truly integrated and comprehensive manner. Furthermore, only a small proportion of these make specific reference to the problems encountered in underdeveloped or tropical regions. A single writer is rarely capable of writing with authority on the full range of disciplines necessary for such work. On the other hand the collected papers of individual specialists generally lack the necessary cohesion. Kneese and Smith (1966) provide a stimulating collection of papers albeit with a rather heavy bias towards economics to the neglect of the environmental and biological sciences. Furthermore, the majority of papers are directed towards experience in the USA. The scope of Biswas (1978) is broader, in both these respects, but the sheer bulk of contributions adds immensely to the difficulty of assimilating and applying the material. Its value as a research tool is also reduced by the poor referencing of many of the papers and the lack of a comprehensive index. Saha and Barrow (1981) restrict themselves to the subject of river basin planning, the majority of papers being directed towards experience in underdeveloped countries. However, even in this work, although some of the individual case studies are of general interest, an overall lack of cohesion is apparent.

Where individual writers have prepared texts of a more technical nature describing the principles of hydrology, geomorphology, engineering and economics which together govern the management of water resources they have generally achieved a more coherent result. Although written almost twenty years ago two such works, Kuiper (1965) and Linsley and Franzini (1964), remain useful works of reference. More recently Dunne and Leopold (1978) have published an excellent study of the application of the principles of hydrology and geomorphology to the problems of environmental planning. None of these books, however, is directed specifically towards the management of water resources in either tropical or underdeveloped regions.

Collected papers of a technical nature are also likely to result in a more coherent presentation particularly where there is evidence of firm editorial direction. Chorley (1969) has produced a technical work of broad scope which provides a useful introduction to the study of water resources engineering. Diverse contributions to symposia on specific topics may also provide valuable sources for water resources research. The International Association of Hydrological Sciences (1974) has published papers from a symposium on the design of water resources projects in the face of inadequate data. Many of these papers are of particular relevance to underdeveloped regions.

Various writers have confined themselves soley to those technical aspects of water resources management which relate to land use and agriculture. Of these, a number direct a part, or all, of their discussion specifically towards the problems encountered in tropical or underdeveloped regions. Jackson (1977) and Pereira (1973) give such topics detailed and scientific treatment supported by good bibliographies. A rather less comprehensive work, but one which includes discussion of engineering and economic practice in the design of irrigation projects, is that of Olivier (1972).

A large number of technical papers and texts concern only specialized topics. Those which are relevant to a discussion of the hydrology, sediment transport characteristics or environmental and social impact of water resources projects are referred in the introductions to Chapters 3, 5 and 6, of this thesis, respectively.

Before considering in greater detail the contribution which individual disciplines have made to the understanding of the problems of water resources engineering reference is made to two publications which seek to put forward policy formulations to guide government officials in developing countries in their management of water resources.

Papers presented by the United States Agency for International

Development (1962) include a number which seek to relate water management experience in the USA to possible problems in developing countries. A paper by Weber and Hufschmidt is of particular interest. They contend that:

> In the early years of our country, we had to deal with much the same problems now faced by the developing nations - problems of economic growth and nation-building in the context of a rapidly growing population. (p299)

Later in their paper they discuss important differences between experience in the USA and in developing countries thus demonstrating the limitations of such an analogy. Nevertheless the history of river basin planning in the USA, which they provide, and the conclusions drawn from this experience deserve consideration. Large scale, multi-project river regulation works in the USA were, from an early stage, undertaken by one of two Federal agencies: The Army Corps of Engineers was responsible for navigation and flood control works whilst the Bureau of Reclamation was responsible for irrigation developments. Because of the powerful position of the privately owned electricity supply utilities and coal mines, hydroelectric power was always given a subsidiary role in water resource planning. As the study below shows, the position was changed with the creation of the TVA; cheap electricity supply became a principal objective although, ironically, the success achieved by the TVA became an important factor in preventing the establishment of similar river basin authorities in other parts of the USA by provoking the powerful private utility lobby to join others opposed to such ventures. Weber and Hufschmidt also note that:

> By 1950, the principles of integrated planning of river basin development had been worked out in considerable detail. Following the work of the National Planning Board, a Federal interagency committee had developed an excellent statement of the principles and procedures of economic analysis for application to river basin planning. Yet practice lagged behind principle. Most river-basin plans were mere inventories of unrelated projects. (p304)

Such conslusions, together with the fact that the TVA model was not emulated, serve to emphasize that, even in the USA where ideas of integrated river basin development have been most vigorously propounded, water management policies have been determined more by political factors than by arguments of a technical nature. Moreover, the water management problems now being faced in the USA are very different from those which were being faced fifty years ago when the ideas of river basin planning were initially formulated. For these reasons comparisons drawn between experience in industrialized countries and proposed schemes in developing countries may be misleading.

The UN Department of Economic and Social Affairs (1970) prepared a revised edition of its earlier paper (1957) in which an attempt is made to review 'the administrative, economic and social implications of integrated river basin development'. These papers present a comprehensive and detailed 'textbook' for policy makers and planners. Although not specifically directed towards developing countries the document contains frequent references to the specific problems which such countries face. Technical details are, however, discussed only in the most general terms.

A number of attempts have been made to describe the specific contribution which particular disciplines can make to the study of water resources engineering. James (1974) provides an informative collection of papers which reveal the different perceptions and insights from various branches of the social sciences. The contributions of selected disciplines, from the social and the physical sciences, to the study of water resources engineering are outlined below. Such comparisons are of particular interest in relation to the conflict between the two planning approaches outlines above - project planning and river basin planning. Interdisciplinary exchanges frequently centre around particular manifestations of this conflict. The disciplines selected have, on occasion, each been put forward as providing a basis for the co-ordination of water resources planning.

Geographical studies

In the past, geographers made an important contribution to the understanding and knowledge of man's use of rivers in all parts of the world, particularly in the nineteenth century, through the writings of explorers and travellers. Such documents often form the principal historical sources on which studies of the origins of water resources development in Africa and in many other parts of the world are based. More recently geographers have provided case studies of specific projects or of the use of water resources within selected geographical regions or countries. For example, Harrison Church (1963) wrote a useful introduction to irrigation projects in Africa in which he compared the economic, social and physical characteristics of different types of project. Geographers have also been engaged in more detailed studies of such subjects as hydrological and geomorphological processes, communications networks and transportation systems, demographic changes, agricultural development, urbanization and the establishment of industry, all of which are influenced by, or influence, water resources planning. Surprisingly, in view of their earlier contributions towards the development of the concept of river basin planning, relatively few geographers are now actively engaged in broad studies of the effects of different water development strategies. Nevertheless, geographers continue to make important contributions to many interdisciplinary river basin studies. The work of G J Williams in the Kafue Basin is a pertinent example.

In recent years, Gilbert F White and his research associates have provided the most prominent and sustained contribution from geographers, to the study of water resources engineering. In one paper, White (1963a) examined the possible contribution of geographical analysis to river basin development. Among his various recommendations and conclusions he placed particular emphasis on the need to consider 'the full range of possible uses of water management', before the construction of projects, in order that the best choice might be made. Water management, as he sees it, is a highly complex process of optimization:

> Every change in landscape or resource use on a large scale disturbs a complex set of relationships. To do so is not necessarily wrong by upsetting a 'natural equilibrium'; the existing situation may in fact be out of equilibrium ... or a new more productive relationship may be established ... The decision to change may, however, go far wide of the intended goal of lasting human betterment if the strategy of development is built upon narrow and distorted models of these relationships. Nothing less than a systems analysis of the whole complex of natural and social processes at work will yield in the long run a sound basis for decision, and it is towards that we should work. (p420 - 21)

A more recent collection of papers, White (1977), has given more detailed consideration to the environmental effects of river development. In an informative introductory paper, White also traced the development of ideas of water resource management into the 1970s. He noted four important changes in earlier approaches to integrated river development in order to take account of the use of both engineering and social modes of management, the greater recognition of biological and physical effects, the problems of water pollution and the problems associated with regions with special characteristics such as urban areas or areas dependent on a common groundwater resource. He also identified three areas where further scientific research was particularly necessary; the effects of long-term climatic change, the identification of the broadest possible range of alternative strategies of development and the assessment of environmental impacts.

Finally, White has been intimately involved in another area of study relevant to the management of river basins: the investigation of human response to the risk of natural hazard. An important collection of papers, White (1974), considers a wide range of hazards. The bulk of the work is, however, closely related to river regulation and, in particular, the risk of floods. Particular emphasis is placed on the need for further research into the way in which people at risk from a certain hazard perceive that hazard and respond to it. In an earlier paper on a similar subject, White (1965), placed emphasis on the divergence between the modern analytical approaches to water management and their practical application:

> the gap between scientific knowledge of optimal methods and their practical application by farmers, manufacturers and government officials is large and generally widening. (p251)

From the foregoing discussion it is apparent that geographers, besides having provided an important contribution towards the original concept of river basin planning, have attempted to develop the links between the physical and the social aspects which are necessary for successful river basin planning.

Economic studies

Economists, having developed certain theoretical and analytical techniques, have been predisposed towards undertaking studies which are susceptible to such analysis. In the field of water resources the limitations of their techniques restricted them, initially, to studies related to single project planning. Although such a limitation would appear to place a considerable constraint on the usefulness of their work economists have for many years taken a prominent role in the management of water resources. This has been true both in industrialized and underdeveloped countries as a result of the great importance which is given to 'economic efficiency' in the organisation of most present-day societies. A number of economists have presented detailed discussions of the application of economic theories to water resources development.

Eckstein (1958) provided an introduction to the application of benefit-cost analysis to water resources projects which has become a classic in the evaluation of single purpose projects. Krutilla and Eckstein (1958) showed how such an analysis might be adapted for the evaluation of multiple purpose projects. Others such as Clark (1967) have attempted to refine the methodology for a specific aspect of water resources development; in this case, irrigation. James and Lee (1971) have provided a detailed and comprehensive review of the theory and practice of economic analysis as applied to water resources projects. They attempt to lay the basis for rational water management and planning taking account of social welfare objectives.

Although other publications might also have been cited, those referred to above provide a broad introduction to the economic analysis of water resources projects and serve to illustrate some of the inherent problems of such analysis. On the one hand, Clark maintains not only that economic analysis is fully capable of providing direct comparisons between alternative projects but also that the results of such analysis should be the sole basis on which investment decisions be based. Rejecting earlier attempts to make allowances for 'secondary effects' of projects he asserts:

> Irrigation schemes must now be judged on their direct economic costs and returns. (pviii)

Eckstein, on the other hand, acknowledged the limitations of the benefit-cost methodology. He states that:

> A benefit-cost ratio of 1.0 does not mean that a project will actually produce more benefit than its cost even if the forecasts of prices prove to be correct, and hence the analysis is not yet a proper means of determining how much money should be spent on the various programmes. Nor is it possible to assume that projects in different fields with equal benefit-cost ratios have the same economic merit, thus restricting the technique primarily to the comparison of projects in the same field. (p273)

Further problems arise when more complex developments are envisaged. Krutilla and Eckstein have drawn attention to some of the difficulties involved in analysing multiple purpose water developments even in countries such as the USA where considerable quantities of economic data are readily available. As a final note they state:

> ... this study may serve to emphasize that it is difficult, if not impossible, to generalize as to what constitutes the most efficient approach to the development of water resources. Our conclusions have varied significantly, depending upon the specific conditions in the individual cases. Moreover, it is desirable to re-emphasize that an efficiency solution to a water resource development problem need not necessarily be the socially desirable solution ... (p277)

Maass (1965) provides a graphic illustration of the shortcomings of the type of economic analysis in which desirable social effects resulting from a project are included only as 'secondary benefits':

> If the objective function for a public program involves more than economic efficiency - and it will in most cases - there is no legitimate reason for holding that the efficiency benefits are primary and should be included in the benefit-cost analysis, whereas benefits in support of other objectives are secondary and should be mentioned, if at all, in separate subsidiary paragraphs of the survey report. Using the current language and current standards, most of the benefits to the [North American] Indians of the Indian irrigation project are secondary benefits. How silly! (p314)

Undoubtably economic methodology is being continually refined, as demonstrated by James and Lee, but, as in all types of mathematical modelling, the use of a more complex multi-function model is no automatic guarantee that the results will approximate more closely to the reality of the social and physical system. In many cases the complexity of the model makes it more difficult to identify its limitations.

Despite the central position economic analysis has been given in the evaluation of water management schemes there remain serious difficulties in relying solely on its methodology, particularly in the assessment of multiple purpose projects or river basin development plans. Practitioners and critics alike have suggested that the results of economic analysis are unlikely to provide an objective basis on which to compare alternative projects unless those alternatives have similar characteristics and have a limited range of impacts. Assessment of the full range of alternatives, as demanded by G F White and others, has rarely been attempted by economists despite the fact that the concept of the 'opportunity cost' of particular capital investments is now widely recognised. One of the few published studies which attempts to compare, by economic analysis, two radically different alternatives in the use of available resources is that of Davidson (1969). His retrospective analysis of investments in irrigated agriculture in Australia compares the present returns with possible returns had the same investment been made in dry-land agriculture. Were it possible to broaden still further the scope of such studies the results would undoubtedly show that the previous narrow interpretation of 'economic efficiency' rarely resulted in the most rational and effective overall use of available resources. Moreover, economic analysis remains poorly equipped to evaluate the 'secondary' or 'side' effects of projects. Maass highlighted the problems in the treatment of social effects. His criticism is equally applicable as regards environmental effects. In both cases the effects are complex and far-reaching and are, as a result, unlikely to be readily susceptible to formal economic analysis.

<u>Ecological studies</u>

In recent years ecologists and environmental scientists have become increasingly involved in studies of the impact of water resources projects. Their response to the environmental changes which have resulted from human interventions in river basins have been diverse. At one extreme Black (1973) regards all hydraulic works as polluting the environment:

> It is impossible to insert into a stream/watershed system anything as gross as a major flow obstruction and not have adverse, far-reaching, irrevocable, and usually permanent consequences. (p253)

The study of the Kariba Project by Balon (1978) appears to have been undertaken on this premise. At the other extreme there are ecologists who see ecology, which in itself is an interdisciplinary science, as capable of being broadened to include analysis of the place of the human species within the dynamics of a changing environment. Rzóska (1978) adopts this approach as indicated by the broad scope of his case studies of the Nile, Zaire and Amazon rivers. For him 'one of the new formulations of theoretical ecology' derives from a paper by Curry (1971) who is himself a geologist. Curry's attempt to define a river is worth quoting at length:

> The equilibrium of river systems is manifest in the tendency of the river to maximise the efficiency of the energy received and utilized, balanced against its tendency to make the efficiency of this use constant through time. These opposing tendencies which ... are fundamental to all natural physical systems such as biotic communities, define the conditions of balance in river systems, or ecosystems, and are time independent ...
>
> The two opposing tendencies are considered by geomorphologists under the theories of minimum variance and minimization of work. Biologists may be most familiar with these opposing tendencies through Garrett Hardin's theorem which states that one cannot simultaneously maximise efficiency and stability in biologic systems. These concepts and their inter-relations define river systems in as fundamental a way as the second law of thermodynamics defines quantifiable closed physical systems. (p11 -12)

Curry uses these concepts to describe the natural hydraulic processes which govern the channel form and profile of a river system. He also shows how attempts by engineers to modify a channel produce results which are governed by these relations. The concepts have wider application which could include natural hydrological and ecological processes as well as the effects of other types of human intervention in river systems. For example, in the operation of a retention system the greater the attempt to maximize one output, such as electrical power production, the greater will be the risk of long-term instability not only in the production of that output but also in other parts of the environmental system influenced by the flow regulation. That economists overlook this fundamental behaviour of natural systems in their quest for 'economic efficiency' lies behind much of the criticism levelled at them by ecologists.

In fact, ecologists rarely present the problems of environmental management in such fundamental terms. Many are concerned, soley in identifying the inter-relationships which exist in small areas selected from the complexity of the total environmental system, or those affecting a limited number of species, for example, fish fauna. As a result, although ecologists have contributed useful case studies on effects of river regulation works, they have frequently failed to enlarge the understanding of their full environmental impact. In tropical and under-developed regions there is a further difficulty in that ecologists have rarely been able to evaluate the influence of a particular project because of the lack of adequate information about the environmental system before the construction of substantial works. Two of the more comprehensive collections of papers relating to the environmental effects of the regulation of river systems are those of Oglesby et al. (1972) and Ward and Stanford (1979). Neither of these, however, gives adequate consideration to the requirements of man as part of the environmental system.

A number of useful collected writings by ecologists have been published which are specifically relevant to large reservoir projects in tropical regions. They are reviewed in Chapter 6. It may be noted that in these the human element is generally excluded except as regards the resettlement of people displaced from the inundated parts of the basin.

Social considerations have, however, been inlcuded in a number of general statements, which ecologists have helped to formulate, concerning the need to increase the scope of current pre-construction evaluating procedures for water resources projects. The statement published by the UNESCO Programme on Man and the Biosphere (1976) in reference to all major engineering works is typical:

> Major engineering works - such as river basin projects and new communications routes - are favoured instruments of development, and can result in considerable economic and social benefits to

> the peoples of the countries concerned. However, the anticipated levels of benefits of particular engineering schemes have sometimes proven illusory, in part because the environmental and social costs attendant with any such scheme were either ignored or not anticipated ...
>
> While the primary effects of an engineering scheme can usually be predicted with an acceptable degree of probability, the secondary and tertiary effects remain obscure and subtle. These effects may, however, affect society more profoundly than the primary effects. (p5)

Nevertheless, ecologists have so far failed to achieve more than a subjective and fragmentary assessment of such secondary and tertiary effects in the majority of cases. This is one of the principal reasons why their warnings are, in general, still ignored by planners. Even in North America, where 'environmental impact assessments' (which also include assessments of social impact) are prepared for all major projects, there have been few occasions when constructive exchanges between ecologists and planners have occurred.

Social, political and legal studies

Various disciplines have contributed to the study of the social, political and legal aspects of the planning and administration of water resources engineering. In reviewing this work it has been necessary to restrict the discussion to those areas which are directly relevant to the present study.

Few detailed studies have been undertaken of the social and political significance of water resources planning within particular national economies although students of government have undertaken studies of the different administrative measures adopted. Generally the development of water resources, from small-scale supply projects to large-scale regulation works on rivers, is under the control of central government. Where water is considered a critical resource, as in the RSA, water resources management becomes a high priority for the government and a strong national policy may be formulated. In many underdeveloped countries, where water is also in critically short supply both in rural and urban areas, the management of the resources is made more difficult by the shortage of finance and of technical and managerial skills. At the same time there is frequently a desire, on the part of political leaders, to undertake large-scale water resources projects for their prestige value. Clearly the problems vary from country to country. Vohra (1975), for example, criticized previous water management policies in India for their lack of administrative co-ordination, for heavy concentration on large-scale projects which took all the available technical and financial resources, for not considering the possible implications resulting from environmental degradation, for neglecting an important part of the available water resources (groundwater) and for underutilization of the capacity of existing projects. In China, according to Shang-Kuei (1975), large projects continue to be built but there has also been considerable priority placed on the building of small projects, adapted to local conditions, for the conservation of soil and water. One of China's strengths has been its ability to mobilize vast numbers of people, in the agricultural slack period, to build the necessary projects.

Whilst such studies concentrate on the formation and significance of government policies, at the other extreme many research workers have been concerned with the degree of popular participation, at local level, in project planning and with the social effects of project implementation. Chief Bright Nalubamba (1978), speaking of the Kafue Basin Project, made an eloquent statement of the attitude of many rural communities to large dam projects, planned by government officials without local participation, in these terms:

> Whatever a government does in an area for the benefit of the people, it must involve the people, no matter how small the involvement. In Tonga we have a saying, 'even if you can't contribute much you should give what you can'. If the government comes in with a project but does not involve the people, then my fear is that they will shun it, saying that it is a government thing, let them organize it. You then have to import labour, to import everything, even if there are things that the villagers could do for themselves. This is a false way of development, for the people must be involved, and must contribute ...
>
> It may be true that when you brought your machinery, etc., to Namwala to put up the dam you didn't need their labour and you didn't need any technology from them: but you should have taken them in to account, because sooner or later they will be involved, even if they were not involved right at the beginning. (p51)

A particular aspect of the local impact of reservoir projects, which has been studied in detail by social anthropologists, is the process and effect of resettling the people displaced from the reservoir basin. The literature on this subject is studied in detail in Chapter 6. Since much of the literature on political and social effects of water resources management has centred around discussion of various types of administrative authority, in particular the autonomous river basin authority, further reference is made to such questions in the subsequent section on the Tennessee Valley Authority.

Legal aspects of water resources have been studied in considerable detail and throw light on political questions both at national and international level. Utton and Teclaff (1978) provide a valuable collection of papers which address a broad range of legal and administrative questions the majority being directed towards experience in North America. The papers edited by Nanda (1977) are of similar scope. Teclaff (1967) produced a meticulous and informative study of the river basin as a legal and political concept. His work covers both the historical origins of the concept and its role in the management of water resources in many countries of the world as well as on international rivers. Le Marquand (1977) has considered the political and legal problems resulting from attempts to achieve international co-operation in the management of river basins. His theoretical overview and detailed case studies are primarily concerned with international environmental and development problems in North America and Europe. Fox and Le Marquand (1976) attempted to generalize this experience for application in other parts of the world. Menon (1975) was also concerned with the development of international rivers throughout the world. He drew attention to the fact that the legal principles had, in general, been established, with regard to the development of shared rivers, but that the formulation of those principles into global conventions of international law was weak. He stated that:

> International water law is a relatively less developed branch of the law of nations. Only two general international conventions deal with international rivers. One is the 1921 *Bareclona Convention on the Regime of Navigable Waterways of International Concern*, which is mainly concerned with navigation. Forty-two states signed the convention; it is only in force in twenty states now ... most of these states ... have no rivers to which the

> convention can apply. The second international convention is the *Geneva Convention Relating to the Development of Hydraulic Power Affecting More than One State*, 1923. The guiding principle of the convention is that of facilitating the exploitation and increasing the yield of hydraulic power. Out of the eleven states ratifying the convention, 'there are scarcely two of them which may be called riparian states ...' (p444)

A particular problem associated with the management of international rivers is that the complex legal problems related to environmental protection and the control of pollution are transferred into the international sphere. Teclaff (1978) sets the problems of legislating for environmental protection within the context of water resources management.

Before concluding this review of the literature on political aspects of water resources management the importance of studies into colonial and post-colonial political and economic systems, economic dependency and world trade, multi-national companies and the transfer of technology should be noted although no detailed references will be presented here. Such studies are of particular significance in cases where a large capital-intensive project is built in a poor country using foreign capital. A particular feature of certain hydroelectric projects is their dependence on a single or principal market for electrical power which is under foreign control, for example a multi-national company's aluminium smelter (as in the case of the Volta River Project in Ghana) or a more developed electrical power network in a neighbouring country (as in the case of Cabora Bassa). Large irrigation projects, on the other hand, often depend on unstable world commodity markets for their economic success.

Technical studies

In general, engineering and technical expertise has been protrayed, in recent years, by politicians and planners simply as a tool which can be directed towards the realization of whatever objectives they have selected. Scientists and engineers have largely accepted this interpretation of their role although some have argued that a greater appreciation of the social, political, economic and environmental effects of technology is needed within the technical professions. In particular, where developing nations are involved, there have been attempts to discover 'appropriate technologies'. For many this term implies a particular type of technology: usually simple, small-scale, locally produced, low cost and non-polluting; see, for example, many of the examples provided in such works as Cook, Dickinson et al. (1973), Congdon (1977), Jéquier (1976) and Dunn (1978). Others maintain that it is meaningless to talk of 'an appropriate technology' except within a particular social, political, economic and environmental context. Dickinson (1974) has used the phrase 'socially appropriate technology' to emphasize this distinction. In his study of water supply in developing countries Pacey (1977) also made this distinction. Nevertheless, many engineers continue to regard the study of social, political, economic and environmental factors as outwith their legitimate area of concern.

In the regulation of river systems, engineers were initially predisposed towards the single project approach because it provided clearly defined, albeit limited, technical objectives. Nevertheless, with the establishment of river basin development schemes and multiple purpose reservior projects new ideas evolved. The earliest papers which discussed multiple purpose reservoir operation emphasized its advantage - the achievement of additional benefits for the same initial investment - without fully discussing the technical difficulties. The TVA engineers were able to devise operating procedures for their system of reservoirs which demonstrably reduced flood discharges downstream whilst achieving the required power generation and navigation objectives. In addition, through a carefully controlled cycle of drawdown, considerable success was achieved in eradicating the local species of malarial mosquito. In describing these successes, Blee (1945), although emphasizing the need for careful co-ordination within the system and the use of operating rule curves to ensure the required level of electrical power output, does not explicitly refer to any conflict or trade-off between the operating procedures required to achieve the different objectives.

There is evidence of an increasing awareness of possible conflicts in the operation of multiple purpose reservoirs, and a desire to place their study on a more rational basis, amongst a number of the engineers who contributed to a symposium organized by the American Society of Civil Engineers (1950). A paper by Malcolm Elliott on multiple purpose reservoirs in relation to flood control and navigation noted that the two would probably be in conflict. Moreover, he maintained that unless floods are of a strongly seasonal nature reservoir capacity allocated for flood control must not be used for any other purpose. As he put it:

> It is particularly important that the public not be assured flood control benefits from a reservoir unless the storage capacity for that purpose is kept available. (p796)

R A Hill in a paper summarizing the proceedings made a similar point noting that unless reservoir storage is 'pyramided' - specific parts of the available storage being reserved soley for specific purposes - then conflicts are bound to arise. Such an operating system is, however, equivalent to a series of single purpose reservoirs operating independently. The delegates could not, in fact, agree about a suitable definition for a multiple purpose reservoir. The preparatory committee had suggested that:

> the term 'multiple-purpose reservoirs' should include all reservoirs actually designed and operated to serve more than one function and that it should exclude those whose design and operation are controlled by a single function, even though other beneftis accrue as by-products. (p790)

Hill in his concluding remarks, however, maintained that the latter should be included. Subsequent writers have never satisfactorily resolved this difference. Another point to note from the symposium was the widespread belief in the capability and suitability of economic methods (benefit-cost analysis) to resolve questions of storage allocation in the design and operation of multiple purpose reservoirs. Nevertheless, in the reported discussions delegates appear to have considered the formal papers to be too narrow in scope. Questions which they thought had been neglected included the operation of reservoirs with inadequate hydrological data, discussion of the 'economic life' of a project, the effects of siltation, health implications and administrative aspects. Certainly these engineers were not constrained by any narrow technical interpretation of their legitimate area of involvement. Incidentally, the questions which they raised are among the principal questions considered in this thesis in respect of the Cabora Bassa Project and are also important in the operation of reservoir projects in many developing countries.

Since 1950, there has been a more general acceptance amongst professional engineers that the operation of multiple purpose reservoirs involves conflicts and trade-offs. For example, Thomas (1976) lists the following as the most common usages of multiple purpose reservoirs: (i) water supply, (ii) irrigation, (iii) silt retention, (iv) transportation, (v) flood mitigation, (vi) electricity generation, and (vii) recreation and beautification. He continues:

> For (i), (ii), (iv) and (vi) the aim is to keep the reservoir full to ensure continuity of supply in dry periods; for (v) the reservoir level should be kept low in order to have storage available for part or whole of the flood inflows; whilst for (vii) the public desire a constant level in the reservoir. Resolution of these conflicting requirements is involved. (V1, p10)

In practice the significance of such conflicts is rarely appreciated before the project is completed and inadequate provision is made for their resolution. Where different aspects of a project's operation are under the control of different government agencies the conflicts may polarize into inter-departmental disputes. Benedick (1979) describes such a situation in the case of irrigation, power generation and flood control requirements from the Aswan High Dam:

> There is evidently a constant pull-and-tug between the ministries concerned in drawing up the annual water release budget. To some extent, it involves a trade-off between agriculture and industrial development. Up until now, at least, irrigation requirements have been deemed pre-eminent. (p129)

Engineers have been engaged in investigating techniques to find an objective way of resolving such conflicts through optimization procedures. A common method used is to analyse the effect on the benefit/cost ratio of various operating procedures. The shortcomings of such a method are clearly illustrated by reference to a paper by Lotti and Pandolfi (1978) which presents a typical design study for a large river in an undisclosed part of Africa. First, optimization methods become considerably more complex where more than two variables are considered; in the study by Lotti and Pandolfi only the optimum combination of irrigated area and hydroelectric generator capacity is investigated. Second, considerable simplification of the physical system is generally necessary; the most significant simplification in this and many other studies is in the representation of the hydrological input data. Few models are capable of handling the stochastic character of hydrological events in a realistic manner or of incorporating functions which adequately represent the economic and social risks which rare events (either floods or droughts) may bring. Lotti and Pandolfi use only the mean annual discharge as their primary hydrological parameter and, although they repeat their analysis using discharges from a 'poor' year, no estimate of the probable frequency and significance of such extreme events is given. Young (1968) has shown how simple probabilistic functions may be used to represent hydrological inputs to a reservoir management model. However, in his model he does not attempt an optimization of output, as such, but rather the evaluation of an operating rule curve which will enable a primary output (flood protection) to be maintained whilst also providing a secondary output (increased flows in the dry season to improve water quality). More recently, multi-function optimization models have been developed for use with electronic computers and have been applied, in particular, to problems involving water quality; see, for example Haimes et al. (1975). The work by Loucks et al. (1981) provides an up-to-date and detailed assessment of mathematical models as applied to both water quality and water quantity problems. In the latter category stochastic variations of river discharge have been incorporated into certain models by the generation of synthetic streamflow data showing similar statistical properties to those of the recorded data. Nevertheless, despite all these advances Loucks et al. are at pains to stress the limitations of modelling which they regard:

> very much as an art ... Stochastic models ... both for reservoir operation and for river basin project design and operation, are relatively crude compared with the real prototype. (p374)

Engineers have also become involved in the planning of integrated river basin development. Much of the work of the TVA was planned and supervised by engineers and other technical specialists. However, the engineers view of integrated river basin development is frequently narrower than that of the geographer or ecologist. For example Olivier (1969) has written about integrated river basin development with particular reference to the RSA. His paper covers a broad range of technical and economic issues, including the problems of erosion and siltation, and argues the need for inter-disciplinary co-operation, multiple purpose rather than single purpose projects and a basin-wide view of development. However, he makes no specific reference to the important environmental, social and administrative issues involved in such development. Furthermore he believes that systems analysis and economic evaluation, by themselves, provide 'a sound basis for meaningful forward planning' for developing river basin potential.

The adverse environmental effects of their work have provided the basis for much of the criticism directed at engineers over the years, in the design of water resources projects. Such criticism is often valid although in isolated cases, where special attention has been paid to minimizing certain adverse ecological effects, it has been claimed, with some justification, that projects have actually improved the environment. The neglect, by engineers, of environmental considerations has arisen, according to Thomas, because:

> during the last half century the dominant concern in water resources development has been engineering feasibility ... Intangibles - whether good or bad - were omitted from studies because no one was prepared to put a monetary value on them. (V1, p13)

Nevertheless, Thomas suggests that there was a move away from reliance on the rigid application of economic criteria during the early 1970s which resulted in an increased willingness on the part of engineers to discuss environmental questions. This resulted in the inclusion of a question about environmental effects of dams in the Eleventh International Congress on Large Dams; in Madrid in 1971, which drew a total of fifty-nine papers.

The Tenessee Valley Authority (TVA)

The inception of Portuguese plans to exploit the resources of the Zambezi valley has been described in the following terms:

> The multiplicity of questions linked to the river, and their relationship with economic development, was found to provide a parallel with the case of the development of the Tennessee River region of the USA, known as the *TVA scheme*. This inspired the Government - through the then Minister and

> Undersecretary of Overseas Territories, Prof. Raul Ventura and Engineer Carlos Krus Abecasis - to constitute, in 1957, the *Missão de Fomento e Povoamento do Zambeze* with a view to 'undertaking a systematic survey of the resources of the hydrographic basin of the River Zambezi within Mozambique, to organize plans for their exploitation and development and to design the necessary projects'[33].

Although rarely acknowledged in subsequent reports it is clear, both from this quotation and from a study of the contents of the library which was assembled in Tete, that the Portuguese planners who authorized and undertook the studies of the Zambezi valley were strongly influenced by the experience of the TVA. Similar influence on a wide variety of basin development schemes throughout the world has been recorded. This influence is considered in more detail below following a discussion of the Authority's principal characteristics and achievements.

A relatively large number of books and papers have been written about the TVA. Each provides a slightly different view of the Authority although the majority have been written either by employees of the TVA or by strong supporters of its ideals. A good general history of the TVA is provided by Owen (1973). Her work is also more recent than many of the major texts. Interesting monographs have been written by at least two of the former Chairmen of the TVA Board of Directors, see Lilienthal (1944) and Clapp (1955). Both writers lay emphasis on political aspects of the TVA; the former on its potential for increasing decentralized democratic participation and the latter, amongst other functions, as an instrument for regional development and as an initial step towards the implementation of a national energy policy. Huxley (1943) wrote a short introduction which concentrates on the principal achievements of the TVA in physical planning and the architectural aspects of its engineering works. Three studies provide a more analytical approach. Pritchett (1943) studied the organization and administration of the Authority. The detailed study by Finer (1944) was undertaken with the specific aim of identifying those features of the TVA, in particular its administrative features, which might serve as a model for similar development schemes elsewhere. Finally, Selznick (1949) undertook a careful investigation of how far the TVA's social and political ideals were put into practice, in agricultural development at a local level.

The Tennessee Valley Authority Act, passed by Congress on

18 May 1933, was entitled:

> An Act: To improve the navigability and provide for the flood control of the Tennessee River; to provide for reforestation and the proper use of marginal lands in the Tennessee Valley; to provide for agricultural and industrial development of said valley; to provide for national defense by the creation of a corporation for the operation of Government properties at and near Muscle Shoals in the State of Alabama, and for other purposes.[34]

To achieve these broad objectives the act established a river basin authority with wide powers and a high degree of autonomy. Its three-man board of directors was appointed by, and directly responsible to, the President of the USA and its work was financed by large appropriations from the Federal budget approved on an annual basis by Congress. Within ten years of its establishment, the TVA was exciting considerable interest both within the USA and in other countries; its achievements and ideals were already being regarded by many as providing a symbol and model for widespread application in the future. Pritchett (1943) summed up this euphoric view:

> No other public instrumentality of our times has seemed to have more symbolic meaning, more usefulness as a tool, more promise for the future. (p314)

Yet, reading through the many tributes to the TVA which have been written, there appears to be no consensus on which of the TVA's ideals or accomplishments have constituted the principal elements of its success nor on the preconditions necessary for such success.

For some, the core of the TVA's early success is to be found in the technical and environmental achievements which resulted from its ability to develop the Tennessee river catchment as a single unit. The TVA exercised control over the resources of the basin in a rational manner 'governed', according to Lilienthal,[35] 'by the unity of nature herself'. Elliot (1973) has provided a useful introduction to the achievements and environmental effects of the impressive programmes of engineering works for which the TVA is responsible. In a catchment area of 106×10^3 km², from which the mean annual discharge is approximately 57×10^9 m³, a total of thirty-three major dams now regulate the river. Together their reservoirs provide a guaranteed flood storage capacity, during critical months, of 15 x 10^9 m^3 and, through centralized control of this system, significant downstream flood alleviation has been achieved. Nine of the dams, located on the main river, have created a navigable channel 1050 km in length, with a minimum depth of 2.75 m, stretching from Paducah to Knoxville. Although operated, principally, for flood control and navigation the dams, which together have an installed capacity of over 3600 MW, also provide large quantities of electrical energy. In addition requirements for municipal water supply, for mosquito and aquatic weed control, and for recreation and wildlife are incorporated into the operating procedures for the reservoirs. In the catchment areas serious problems of degradation and erosion, which previously caused great loss of agricultural land and resulted in heavy sediment loads in the rivers, have been arrested and reserved. This has been achieved partly as a result of agricultural improvements stimulated by the TVA, including the use of super triple phosphate fertilizer produced by the TVA using an electro-chemical process developed by its own scientists, and partly through a concerted afforestation programme as a result of which 58% of the basin is now wooded. To add emphasis to the importance of the TVA's technical and environmental achievements it should be noted that the first two Chairmen of the TVA Board of Directors had technical rather than administrative backgrounds; A E Morgan (1933-8) was a civil engineer and H A Morgan (1938-41) was an agricultural scientist. Some subsequent chairmen have also been engineers.

More recent developments in the technical and environmental spheres have, however, clouded the TVA's image. Critics such as Branscome (1975) have condemned the TVA's decision, taken in the late 1940s, to begin generating electrical power from coal. Thermal generation has resulted in atmospheric pollution, in thermal pollution of the rivers and in large scale strip mining operations which have scarred parts of the basin. Many people now believe that the TVA should have shown a greater commitment to environmental protection, land reclamation and energy conservation at that time. Further criticism has arisen from concern over the possible environmental dangers of the TVA's heavy involvement in nuclear power stations from the early 1970s onwards.

Without denying the reality of the TVA's technical and environmental achievements, some observers consider that the Authority's most significant achievements lie in the social and economic spheres. Federal interest in the Tennessee Valley centred, initially, around a single project for the production of nitrates for munitions (or, in peacetime, fertilizers) at Muscle Shoals but it was in response to the serious economic depression which affected the USA in general, and that region in particular, that the TVA was, finally established. Like other New Deal ventures it was designed to create employment and to provide the necessary conditions for economic growth. These objectives were achieved in dramatic fashion. The steady depopulation of the region was halted and then reversed through the creation of employment opportunities in construction and forestry, in the manufacturing industries, attracted to the region by cheap power and cheap transportation, and in the related service industries. Agricultural development, together with access to cheap electricity by the rural population, also contributed towards a sharp rise in private incomes and in the general standard of living (although these have remained below average for the USA). The disruption caused to the 15 000 families who had to be resettled from reservoir basins and to those displaced more recently by the strip-mining of coal is considered by many to have been far outweighed by these benfits. The TVA's policy of providing abundant supplies of cheap electricity on a tariff scale which decreased markedly as consumption increased has been identified as the single most important factor in the economic transformation of the region. McCraw (1976) and Street (1980) have provided useful introductions to the role of electrical power in the history of the TVA. Street's paper shows how, initially, industries demanding large quantities of energy were attracted by the TVA's low tariffs. This has changed with time and much recent industrial growth has been in less energy-intensive industries. McCraw provides information about the TVA's relationship with the Federal Government and with privately owned electrical power utilities. In particular, he has shown the strong influence which World War Two had over the TVA's development in that it brought a rapid increase in the demand for aluminium and also the establishment of the Government's Oak Ridge plant for processing nuclear materials. This plant subsequently grew into the TVA's largest single consumer.

Finally, some observers have placed considerable emphasis on the political and administrative aspects of the TVA. The TVA was established as a public corporation with a high degree of legitimacy (its three-man board of directors being appointed directly by the President), with a high degree of autonomy in its use of the large financial resources available to it (receiving in its first nine years, almost US $700 million in appropriations from Congress[36]) and with an extremely broad sphere of responsibility within a clearly defined region (having, in addition to its responsibilities for the physical development of the basin, 'the explicit mandate to achieve specific, if perhaps not wholly clear, economic and social goals'[37]). Teclaff[38] concluded that 'the TVA enjoys greater independence and flexibility than any other government department or agency' in the USA. Furthermore, having been established in the inter-war years when concern was being expressed in the USA with political developments in both Germany and the Soviet Union, many people came to see the TVA as an instrument for renewing and preserving democratic government. In particular, the establishment of the TVA achieved a transfer of national resources to a seriously depressed region, it overcame the problems of inter-agency disputes and frequent political changes in development planning, it enabled an entirely new administration to be created for a particular task free from the established system of bureaucracy and patronage and, because of its decentralized nature, it provided a unique opportunity for local participation in decision-making. Lilienthal (1944) placed considerable emphasis on the last of these. An enthusiastic and capable team of staff was created which was dedicated to 'TVA ideals' and showed a large measure of responsibility towards its work.

It is not surprising, in view of the large number of established interests upon which the TVA has impinged, that the Authority has been the centre of considerable controversy. Those within existing state and federal agencies criticized the TVA, amongst other things, for being a superstate with too much power and too little public accountability. For example Stephens and Horner (1945), of the Corps of Engineers, wrote:

> The 'Authority' principle is decidedly undemocratic, since all development is in the hands of a small group appointed by the President, with no direct responsibility to the people of the basin.

More recently environmentalists have also criticized the TVA's lack of accountability. Branscome (1975) found evidence for this in the TVA's contracts with strip-mining companies for the supply of coal, in its timber harvesting operations, in its nuclear power station programme and, ironically, in its freedom to raise its electricity tariffs without reference to Congress. In its early years, it was the cheapness of the TVA's electricity tariff which brought some of the fiercest criticism. Private utilities complained that the TVA undermined the free-market economy by using federal funds to subsidize its tariffs. Whilst, in this and other controversies which have surrounded the TVA, it is difficult to make clear judgments in the face of considerable political rhetoric, the work of Selznick (1949) has provided the basis for a more objective analysis. He identified significant problems in the attempt to combine democracy and planning concluding, amongst other things, that, despite a real commitment to democratic principles on the part of the TVA's staff, grass-roots participation in the agricultural programme:

> represents a sharing of the burdens of and responsibility for power, rather than of power itself. (p264)

Nevertheless, in the Tennessee Valley the TVA won a degree of public respect and support, during its first two decades, which has been matched by few public agencies. Furthermore, in many small-scale development programmes, the degree of local initiative and control remains high.

Before considering the possible application of the TVA experience to other situations it is worth examining the particular circumstances which contributed towards the successes of the TVA. Kraenzel (1957) identified some of the circumstances discussed below in a comparison he made between the TVA and a proposed Missouri Valley Authority. First, the Tennessee Valley possessed several physical features which made it particularly suitable for river basin development: it is a relatively small river basin with suitable topography; the region possesses valuable reserves of several minerals; the mean annual precipitation is relatively high (1300 mm) and strongly seasonal; the majority of reservoir sites covered low value land but afforded flood protection to high value land downstream; and the reservoirs did not create any new health hazards partly because the breeding cycle of the local species of malarial mosquito could be disrupted by careful reservoir operation. Secondly, the Tennessee Valley possessed several features which favoured its rapid economic development: there was a relatively dense, albeit declining, population; there were several important urban areas already established in the valley; the valley has easy access to the urban/industrial complex of the eastern

USA; and the stimulus to production provided by World War Two occurred when the TVA had become established and was ready for rapid expansion*. Thirdly, circumstances were favourable for the TVA's political and administrative success; the depression and war years prepared people for experiments with new instruments of government and to accept the risks involved; commitment to the war effort also allowed the TVA to purchase land for reservoirs with much less opposition than in peacetime; the TVA was supported by individual politicians, particularly Senator Norris and President Roosevelt, who were strongly committed to its success; it also owed much to the talents and dedication of its early staff, in particular the three members of the first Board of Directors; and, finally, no other agency had previously undertaken substantial development work or planning within the basin. Bain (1965) stresses that importance of this last point:

> a late-arriving federal or state agency which attempts multipurpose river basin development in a basin which is pretty well settled and developed encounters multiple legal and physical disabilities which deter it from approximating to its theoretical potential. (p66)

The two principal vested interests in the Tennessee Valley before the arrival of the TVA were the agricultural agencies (State Extension Services and Department of Agriculture) and the private electricity supply utilities. With the former the TVA reached a working relationship and against the latter the TVA won a protracted legal battle.

Application of the TVA model and other case studies

Scarcely ten years after the TVA's formation Lilenthal (1944) claimed that:

> Among the more than eleven million people who have visited the TVA in recent years have been representatives of almost every country in the world ...
> This same world-wide interest is reflected in thousands of letters from many nations. (p173-4)

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* In studies of the TVA's economic development it is worth noting the important distinction drawn by Kraenzel between the area of the basin proper, the area served by TVA's electricity and the area comprising the seven states which have territory in the Tennessee Valley.

Lilienthal was one of the strongest advocates of the TVA as a model for others to follow. For him the principal lessons to be learned from the TVA's experience were to be found in the level of local participation achieved and in the physical concept of river basin development. Development of resources following the TVA model, he contended, would not only bring benefits to individual regions but would stimulate national and international economies:

> *in any perspective of time, unified resource development anywhere helps everyone everywhere*[39].

Amongst the many who acknowledged Lilienthal's influence over their ideas of water resources planning was the general manager of the Gezira Scheme, Arthur Gaitskell[40]. Similar interest in the TVA model has continued through its history. In 1981 the Chairman of the TVA made a speech calling for the establishment of institutions similar to the TVA on an international basis[41]. One of the more detailed studies which has been undertaken of the TVA as a model for international application is that of Finer (1944). Finer considered that the essence of TVA-type management lay in the creation of a single authority with responsibility for a specific underdeveloped region. He maintained that the region need not necessarily be a river basin but stressed the need to recognize that existing political frontiers are inadequate since they do not, in general, enclose potentially self-sufficient economic units amenable to comprehensive planning. For him the application of the TVA model to the international situation not only involved transcending existing frontiers and institutions but also involved the transfer of capital from developed to underdeveloped regions. The TVA had the financial support of the budget of the USA. Few other underdeveloped regions could command such substantial resources except through international co-operation.

A comparison between the administrative structures of river basin authorities established in various countries since 1940 was included in the study by Teclaff (1967). Although his work is descriptive rather than analytic it serves to demonstrate the weakness of many of these authorities in comparison with the TVA. Few, if any, river basin authorities have the same degree of administrative and financial autonomy or the same wealth of natural resources under their control as the TVA.

El Tayeb (1977) undertook a more restricted comparison of different types of comprehensive water resources development as part of his study of the Gezira scheme in Sudan. His work is of interest because, by comparing selected examples of successful and less successful schemes with similar administrative structures, he showed that the creation of a TVA-type autonomous public corporation was neither necessary nor sufficient for the successful management of water resources.

The TVA remains the most frequently quoted example of a successful venture in river basin development not only because of the limited success enjoyed by many of the other ventures but also because few of the other ventures have been adequately studied and documented.

One of the earliest overt attempts to imitate the TVA was that of the Damodar Valley Corporation (DVC) in the Indian States of Bihar and West Bengal. Although relatively few studies of the DVC have been published, a detailed study undertaken by Hamilton (1966 and 1969), which concentrates primarily on the administrative aspects of the enterprise provides a realistic analysis of its achievements and shortcomings. More recently Saha (1979) has provided a paper which discusses the planning objectives and achievements of the DVC. Jain et al. (1973) describe, in general terms, some of the environmental changes which the DVC has brought. From a study of these sources it is apparent that significant differences between the DVC and the TVA exist. The DVC was conceived primarily in response to flood hazards in the basin although the TVA engineer who formulated the initial plans stressed the potential for comprehensive river basin development. The basin, which has an area of 24 000 km², is less than a quarter the size of the Tennessee basin but, with dense established populations along the river banks, considerable resettlement was needed when the four dams of the first phase were built (approximately 100 000 people were affected). Thus, although it has been possible to provide downstream flood protection this has been at the expense of habitation and agricultural production in and around the reservoir sites. Recently these flood benefits have been eroded by channel deterioration and by increasing population densities in areas of risk. The DVC's main success has been in electrical power generation and distribution although the hydroelectric component of this is small (104 MW installed) and is reserved for periods of peak demand.

A big expansion of industrial and mining activities has occurred in the region. Irrigation has also expanded although the system has not been efficiently planned or maintained. Against this the DVC has failed to arrest soil erosion, with the result that rapid siltation of the reservoirs is occuring, an expensive navigation canal has not been fully utilized and problems created by an ever-increasing population, including health hazards such as that from malaria, are now becoming acute. The DVC's major handicap has been in its relations with the Central and State Governments. Initially, the DVC's creation resolved a conflict between the states which made possible the building of four dams. Since then, however, there has been a steady erosion of the DVC's power by these governments which has left it as little more than a public power utility and has prevented the building of further dams as originally proposed for the DVC's second phase of development.

The experience of the DVC is very different from that of the Khuzestan Water and Power Authority in Iran, also, supposedly, modelled on the TVA. There, regulation is provided by a single reservoir formed by the Dez Dam which was created initially for irrigation and for hydro-electric power generation. Ghazi (1977) provides a critical analysis of the scheme based on the results of a socio-economic study which is relatively broad in scope. Her conclusions highlight social and political aspects of the scheme which are in marked contrast to those of the TVA. At the time of her study the inequitable system of land tenure in the region and the project's dependence on highly mechanized agro-industrial corporations ensured that the majority of the local population had little influence over, and derived few benefits from, the project.

Following the success of the TVA a number of attempts were made by Roosevelt and others to introduce similar river basin authorities into other parts of the USA. Teclaff (1967) cites the American part of the Columbia Basin as one region in which, dispite presidential backing and the introduction of Bills to both Senate and Congress, attempts to create an autonomous public corporation failed. Prior to this the Corps of Engineers had already undertaken surveys for a 'comprehensive plan' of the region, described by Tudor (1945), and at approximately the same time the Bureau of Reclamation was preparing a separate 'comprehensive plan'. Although the Federal Government succeeded in co-ordinating the work of these two agencies in the formulation of a single comprehensive plan, described by Whipple (1951), it was incapable of overcoming the opposition of these agenices to the formation of a TVA-type river basin authority. Events in the Columbia Basin were mirrored elsewhere, for example in the Missouri Valley, where according to the account of Terral (1947), even the formulation of a single development plan involved considerable controversy which was only 'resolved' by assuming the discharge of the river to be greater than in fact it was. A further complicating factor in certain basins has been the existence of fierce inter-state conflict or conflict between basin states and the Federal Government. According to Leuchtenburg (1953), both of these played their part in preventing the formation of a TVA-type administration for solving the flood problems of the Connecticut River.

One of the other basins in which President Roosevelt proposed to establish a TVA-type authority was the Colorado. The early development of this basin was marked by the establishment of several large irrigation projects, planned individually, and reclaiming otherwise unproductive land. The Federal Government became increasingly involved in the management of the Colorado valley as the problems of allocating limited water resources between different irrigation projects, of combatting increasing levels of salinity in the river and of reconciling the demands of alternative water uses and those of downstream uses in Mexico became more acute. The history of the management of the waters of the Colorado and of attempts to resolve these conflicts are discussed in a collection of papers, edited by Peterson and Crawford (1978), which provides one of the most informative multi-disciplinary studies of the problems of river basin development on an international river currently available. A study by Day (1970) of an adjacent river basin, the lower Rio Grande (Rio Brave), with very similar problems is also broad in scope. Day's study is particularly creditable and unusual in view of the fact that it was prepared by a single person. In both these river basins the principal problems arise from over-demand for irrigation water and from poor water quality resulting from saline drainage. As neither of which are problems which will affect the Zambezi in the foreseeable future, few of the conclusions from these studies are directly applicable to the present work.

In the Columbia, Colorado and lower Rio Grande basins a part of each region lies within countries other than the USA and, therefore, international aspects of the management of the resources are important. The problems of international co-operation feature prominently in the management of many large river basins; from information published by the UN Department of Economic and Social Affairs (1970), fifteen of the world's nineteen river basins with areas greater than 10^6 km² cover more than one country as do over half the basins from 100 x 10^3 to 1 x 10^6 km². Teclaff (1967) discusses the small number of cases in which international agreement has been reached in the development of the water resources of such basins. Frequently such agreements have been preceded by periods of conflict which have been resolved only when commitments have been given either by one or more of the countries involved, or by external agencies, to invest large amounts of capital in new projects within the basin. Several basins in the USA provide examples of the former case, (see Krutilla (1967) for a discussion of the economic aspects of the Columbia River Treaty), whilst the Indus basin, in which the World Bank made substantial investments, provides an example of the latter (see Michel (1967)). Where no formal agreement has been made basin states generally proceed more or less independently. For example, on the Euphrates there has been very little co-ordination between Turkey, Syria and Iraq. As a result, according to Catakli et al. (1973), there is a danger that an unnecessarily large number of reservoirs will be created causing unnecessarily high evaporation losses, that reservoir impoundment and operation will not be planned to the optimum benefit of downstream users and that problems will arise over water rights and water quality. Crow (1981) has undertaken one of the few detailed studies available of the origins and effects of political conflict, in the use of water resources, between underdeveloped countries. His case study of the conflict between India and Bangladesh over the division of waters from the Farakka Barrage illustrates the way in which technical ambiguity, which is frequently unavoidable in hydrological studies, has been used by different parties to further their own objectives with the result that decisions have been made less from technical, social or economic merit than as the result of the play of political forces. His work also demonstrates how, in situations of unresolved conflict, the governments of countries in the upstream parts of a basin are generally in a stronger position than those downstream and may choose to ignore protests from downstream unless other factors compel them to seek a resolution of the conflict.

The number of cases in which nations have shown themselves willing to co-operate both in the planning and execution of river basin development schemes is relatively small. White (1963 a and b) has provided details of one of these - the Mekong River Plan - which, in the early 1960s, offered the basis for co-operation between the four basin states but was later abandoned as military conflict in the area intensified. The Mekong River Plan was the first attempt to achieve co-operation under the auspices of the United Nations and, in addition, was one of the few cases in which a serious attempt was made to undertake detailed multi-disciplinary studies of the whole basin before undertaking any construction. The Mekong Commission still exists but is largely ineffective, yet some bilateral discussions of river management have taken place under its aegis.

The study of water resources engineering in Africa

Within the growing literature relating to problems of development in sub-Saharan Africa are some useful studies of water resources engineering. As a general bibliography for sources of technical information and data, Rodier (1963) remains invaluable. Bederman (1974) has also provided a bibliography directed specifically towards Africa which contains useful references on subjects relevant to the water resources engineer. Balek (1977) has used information and data from many parts of the continent as the basis for a description of African hydrology and the problems of water resources engineering. The result is disappointing partly because large gaps in available information and data have resulted in an uneven treatment for different parts of the continent, partly because of the large number of typographical and arithmetical errors which the volume contains and partly because of the omission of reference to information sources from many of the tables of data.

African rivers have also provided material for some interesting case studies in water resources development, see papers presented by Rubin and Warren (1968). Amongst the studies of single projects planned and executed by a single country, that by Hart (1980) of the Volta River Project in Ghana deserves particular note. Following a discussion of the motives of project's instigators and the political processes by which it came to fruition, Hart undertakes a careful analysis of the effects of the project on the Ghanaian people and on their national economy. The study is of particular interest in that it demonstrates the hazards to a country with a relatively underdevloped electricity supply system of undertaking a large hydroelectric project whose output is many times greater than the current level of energy consumption in that country. In Ghana's case this led to dependency on a multi-national aluminium company, over which the government has very little influence, as the major consumer of the project's power output. Furthermore, because the energy demands of this one consumer are high and the tariffs which it obtained low, the remaining electricity consumers in Ghana are subject to high tariffs and are, in effect, subsidizing the aluminium smelter's supply. As a result cheap 'Volta' electricity has not been the anticipated stimulus for economic growth. A similar failure to stimulate rapid industrialization occurred with the Owen Falls Project in Uganda, according to work undertaken by Wilson (1967). In this case the initial excess generating capacity at the dam was only absorbed when the Ugandan Government entered into a long-term commitment to supply power, at low tariff rates, to the industries in neighbouring Kenya. In this respect the project is similar to Cabora Bassa although on a much smaller scale. However, the nature of the Owen Falls Project ensured that virtually no changes occurred in the existing hydrology or ecology of the region, since storage is provided by a natural lake, Lake Victoria, with the result that, unlike Cabora Bassa, Owen Falls can be regarded solely as a hydroelectric project. By contrast, ecological changes are of considerable importance for the operation of the Kamburu Dam in Kenya. The study of this project edited by Odingo (1979) constitutes the first attempt in Kenya, and one of the first in the whole of Africa, to undertake a comprehensive, multi-disciplinary study prior to construction.

Africa also has a large number of international river basins. According to information provided by the UN Department of Economic and Social Affairs (1970) there are 55 international basins on the continent and of the twenty basins with areas over 100×10^3 km^2 only two are not international. In certain cases, such as the Zaire, a single country covers the major part of the basin and, therefore, international aspects of river development have not featured prominently. In other cases, such as the Nile, agreements have been necessary to enable the basins' water resources to be fully exploited. A useful introduction to the history of agreements on the division of the Nile waters between basin states is given by Dickinson and Wedgwood (1980). Egypt, with its established dependence on irrigation water from the Nile has, from the earliest agreements to the present, exerted considerable influence over the details of arrangements for regulating and sharing the river's discharges. Taken as a whole the influence of the Nile's waters on the physical and economic characteristics of the basin states is far-reaching and complex. It includes changes in the delta region resulting from regulation of the discharges, development of the irrigation and electricity supply systems of Egypt and Sudan, development of irrigation and the problems of soil erosion in Ethiopia, development of the electricity supply system of Uganda, environmental changes produced by the Aswan High Dam and possible changes which will occur with the construction of the Jonglei Canal. Some of these aspects have been studied in detail (studies of environmental effects are referred to below, in Chapter 6) although, to date, no studies have been published which have attempted a comprehensive, multi-disciplinary analysis of river basin development for the Nile. Hydrological questions have, however, been considered for the basin as a whole in as far as Egypt's and to a lesser extent the Sudan's, irrigation requirements have been considered in the design of most major projects including the Aswan High, Owen Falls, Sennar and Roseires dams and the Jonglei Canal.

The Senegal valley is unique in the world in that an attempt has been made to establish there a TVA-type authority in an international river basin. The *Organisation pour la Mise en Valeur du Fleuve Senegal* (OMVS) was established, in 1972, by three of the four basin states - Mali, Mauritania and Senegal, see Parnall and Utton (1976). The primary purpose was to provide irrigation in a region affected by serious problems of drought, but the provision of hydroelectricity and navigation, and the need to push back the salt wedge in the delta are also included among its objectives. Watt (1980) provides an informative discussion of the alternative options facing the OMVS and the problems which may arise. He sets this in the context of the region's history and the economic and social distortions which have resulted. A significant problem in any development of the valley is that of persuading farmers to adopt irrigation techniques in place of the traditional floodplain agriculture. Such action would reduce their risk from drought but increase their financial risk. Problems also exist in replacing the existing system of land ownership and privileges. The OMVS has recognised that such social factors are as important as the economic factors on which international agencies, such as the World Bank, base their investment decisions but its present terms of reference prevent it from exercising the full powers of a regional planning agency. Nevertheless, OMVS proposals stress the need to establish decentralized management of irrigation projects and co-operative maintenance of irrigation works. The powers of the OMVS may also be insufficient to resolve differences between member states in the allocation of water if, as Watt predicts, conflicts arise during periods of drought.

From this brief account the vast differences between the OMVS and the TVA are readily apparent. Similarly, Kokot (1949) identified important aspects of economic and hydrological differences between river basins in the RSA and the Tennessee Valley and, on that basis, argued that the idea of multiple purpose reservoir development in southern Africa was inappropriate. He did not, however, consider, whether or not political and administrative aspects of the TVA were applicable.

To conclude this summary of experience in water resources engineering in sub-Saharan Africa studies of three projects of particular significance to the present work are examined. The first two projects in the Kariba and Kafue gorges, are within the Zambezi Basin and detailed discussion of their characteristics is included in various chapters of this thesis, the third project, on the Kunene (Cunene) River in Angola, is included because of the political links between it and the Cabora Bassa Project.

Although a large number of papers, together with a number of monographs, have been written on aspects of the Kariba Project, no single work provides a comprehensive analysis of its impact and influence in the region and no co-ordinated and sustained attempt has been made to undertake multi-disciplinary studies of its effects. The technical details of the project and its construction have been well documented (see Chapter 2). Furthermore, numerous studies were made of ecological changes during the period of impoundment and of the effects on the local population of the initial resettlement (see Chapter 6). Nevertheless, few attempts have been made to monitor the dam's influence on the local population, on the environment and on industrial and mining development in Zambia and

Zimbabwe since the mid 1960s. Nor have serious studies been published on the dam's political and economic importance, particularly during the period of increasing conflict following the Unilateral Declaration of Independence (UDI) by the white government in Rhodesia. Of the available scientific publications, the work edited by Balon and Coche (1974) provides the most detailed introduction to the project, albeit from a rather narrowly defined ecological view-point. The work does contain, however, an extensive bibliography. Of the monographs which have been published, Clements (1959) provides the broadest description of the preparation for, and construction of, the project whilst Howarth (1961) describes the experiences of a small group of people during the resettlement programme. Both are written in popular journalistic style shortly after the events which they describe had occurred and neither attempts an objective analysis of the project. At least two monographs[42] have been entirely devoted to popular descriptions of the operation mounted to save some of the animals stranded by the rising water of the reservoir which received considerable publicity at the time.

By contrast the Kafue Project has been the subject of extensive studies including a creditable seven volume pre-construction survey undertaken by the FAO (1968). The Kafue Basin Research Committee was set up within the University of Zambia to supervise a research project directed towards multi-disciplinary research in the basin. Quartermain (1974) provided a useful bibliography for that project and the Committee, as well as providing research fellowships, has sponsored two important wide ranging seminars the proceedings of which have been edited and published as Williams and Howard (1977) and Howard and Williams (1982). In the second seminar considerable dialogue occurred between research workers, engineers and government officials. From this it became evident that despite the long history of research in the basin considerable ignorance still existed about the hydrological and ecological response of the basin to various forms of regulation. The resulting technical ambiguity was exploited to different ends by the various participants. There appears, at present, to be no agency capable of resolving the conflicting demands on the basin's hydrological resources and of formulating a co-ordinated policy which would take account of the diverse social, economic, political and environmental expectations that have been expressed. As a result electrical power generation has assumed priority.

Comparisons have been made between the Cabora Bassa Project and the Kunene Project in southern Angola. Both were built in former Portuguese colonies in the early 1970s with considerable South African participation in finance and personnel. In each case the prinicpal outputs were to be directed south over considerable distances for the benefit of industrial, agricultural and mining interests of the RSA. In addition, evidence suggests that the RSA made its co-operation over Cabora Bassa conditional upon Portugal's co-operation in the Kunene schemes (see Chapter 2). In physical terms there are some important differences between the two; whereas the Cabora Bassa Project consists of a single dam, creating a vast reservoir, together with a power station supplying transmission lines to the RSA, the Kunene Project consists of a storage dam in the headwaters at Gova, a small dam at Matala, a regulatory dam at Calueque, from where water supplies can be diverted south, and a weir at the Ruacana Falls to supply a hydroelectric station from which transmission lines lead to the main load centres in Namibia. All parts of the project, except the dam at Matala, were built entirely for the benefit of the RSA which withheld its support from other schemes which Portuguese engineers had originally proposed. By contrast, Portuguese engineers believed that the Cabora Bassa Project as built, whilst primarily supplying power to the RSA, would also fulfil an important role in their plans for the development of the Zambezi valley. Christie (1975 and 1976) provides a detailed study of the political and economic significance to the RSA of the Kunene schemes. He showed the strategic importance of these schemes in enabling the RSA to strengthen its economic and political control over Namibia in the face of international pressure to grant that country its independence. To achieve this, South African-controlled mining and agricultural activities in Namibia had to be supplied with water, electrical power and cheap labour. It was for this purpose that the Kunene schemes were designed. In addition, water was to be supplied to Ovamboland in order to enable 'black homelands' to be established to supply the necessary migratory labour and to reinforce the *apartheid* system by reducing the danger of black settlements encroaching upon areas of Namibia reserved for whites. Other aspects of the project, particularly its effects within Angola and the effects on it of political developments since 1975 have yet to be reported in detail.

The individual case studies referred to in the latter part of this chapter illustrate the difficulties which arise in attempting to formulate general conclusions about large scale water resources projects. Each project is set in a unique context with its own physical, environmental, social, economic and political characteristics. The relative importance of these aspects also differs from project to project. Nevertheless, there are certain characteristics which have been observed in a large number of the cases considered and are particularly relevant to projects in Africa. Firstly, such projects are frequently situated in remote or underdeveloped regions, from which little initial information and data are available, and in which little attention is paid to possible adverse social and environmental effects. Secondly, there are generally diverse and conflicting demands made of the project. Invariably the activity which gives the most immediately quantifiable returns assumes priority. In many cases this results in the operation of so called 'multiple purpose' projects solely for the benefit of hydroelectric power generation. Thirdly, the local population is generally given little opportunity to participate in the planning or operation of large-scale projects because of concern by governments and financial agencies to secure a rapid return on investments. Fourthly, many governments have placed undue faith in the ability of a large project, particularly a large hydroelectric project, to stimulate rapid growth of the national economy without paying adequate attention to the other factors necessary for such growth. Fifthly, although the problems of operating large water resources projects are to be found in river basins lying within a single state or nation, many large basins lie across several independently governed territories. In such cases, the difficulty of obtaining inter-state or international agreement on a co-ordinated policy for the development of the basin considerably increases the complexity of the other problems to be resolved. Finally, many hydroelectric projects have been built with installed capacities far larger than could be justified by the current demand for electrical power in the country in which they are located. In such cases long-term agreements have been made to sell power at very low tariffs to neighbouring countries, which are more industrialized, or to energy-intensive industries (particularly aluminium smelting) located in that country but controlled by foreign interests. Such arrangements add further political and economic complexities and, in general, limit the freedom of the country to obtain the maximum benefits from the project for its own population and industry.

The Cabora Bassa Project illustrates, graphically, many of the problems listed above as well as exhibiting several unique features which arise from its historical origins during the final years of Portuguese administration and the period of transition to independence. It is believed that the conclusions drawn from the present study will be of value not only to those who are responsible for determining operating policies for the Cabora Bassa Project but also to those who are planning other water resources projects, both in Mozambique and elsewhere. It often arises that a government's freedom to determine the design details and operating policies of a project are relatively limited once the initial decision to build a dam has been taken. Reference to critical studies of other projects would undoubtedly assist in identifying possible short-term and long-term consequences of the operation of established projects and also help in determining the most effective form for their administration. Acquaintance with such studies might also prevent planners from dismissing too lightly the potential conflicts and possible 'secondary effects' which might arise from the operation of a project under consideration, factors which, experience has shown, are often seriously underestimated in the initial planning phase.

CHAPTER 2

THE HISTORY OF WATER RESOURCES ENGINEERING ON THE ZAMBEZI

The history of the Zambezi valley in Mozambique before 1948*

Iron implements were probably first used in the Zambezi valley as early as 300 AD. By the fourteenth century a relatively sophisticated civilization had developed, in which the cultivation of crops, the construction of large stone buildings and the production of appreciable quantities of gold were achieved. Muslim traders from the Swahili cities, further north, began to inhabit the coastal regions from about the eighth century onwards. By the fifteenth century they had established trading fairs at many inland locations where gold was purchased from African producers. In the Zambezi valley such fairs existed at Sena, Tete, Otonga (30 km north of Lupata), Zumbo and, probably, elsewhere. The traders' ships are reported to have travelled 500 km up the Zambezi paying tolls for passage to African chiefs. Although the international trade in gold was paramount, other products were important in the commerce of the coastal settlements. Their variety serves to indicate the range of skills which were practised, including the manufacture of goods from metal, bone, stone and leather as well as the building and repair of boats. Iron working was particularly important for tool manufacture, in areas where suitable ores were found, and the production of cotton cloth was also of considerable economic importance.

Following the visit of Vasco da Gama, in 1498, the Portuguese began establishing settlements in the region, the first being at Ilha de Moçambique. Their arrival signalled the end of the commercial dominance which had been achieved by the Muslim traders. The principal objectives of the original Portuguese settlers have been interpreted as: first, to provide supply posts for their ships; second, to control the trade in gold and, later, ivory; and third, to acquire personal wealth. Although trade with the local Africans was inevitable, the Portuguese did little to stimulate innovation or increased production.

The Zambezi valley and the escarpment to the south attracted particular interest from the Portuguese because of the reputed mineral wealth. In 1505, they established a settlement at Sofala to control an existing

* This account is based on the sources listed in the Introduction.

trading outlet but, as Muslim and African traders sought to avoid this monopoly, the Portuguese were forced to move further inland. One of their first settlements in the Zambezi basin was at Sena, in 1531, on the site of an existing Muslim fair. Within a few years a similar settlement was established at Tete. Both sites were located close to the Zambezi to enable river transport to be used. The gold was carried to the ports of Moçambique and Sofala, but by 1625 the latter was in decline having been displaced by the port established at Quelimane during the sixteenth century. The Portuguese settlers continued to press inland, establishing a fair at Massapa on the Mazoe River, in 1550, close to an important mining region and building two forts at Chicoa, in 1614, close to where rich silver deposits had been reported. By the end of the seventeenth century their traders had even passed beyond Kariba Gorge, although the furthest inland that a permanent fair was established was at Zumbo, in about 1716.

The region's mineral output, however, did not meet the high expectations of the Portuguese. Although the gold trade was undoubtedly important the settlers failed to locate or control the output from any outstandingly rich deposits. African chiefs succeeded in preserving control over mining operations and were secretive about their locations. Moreover, much of the gold was obtained from alluvial deposits and, where veins of ore existed, they were generally shallow and rapidly exhausted. Silver proved to be extremely illusive and was never obtained in large quantities. Similarly, the trade in copper never achieved great importance. High expectations of mineral wealth in the region persisted throughout its colonial history despite the unpromising yields. More recent proposals for mineral exploitation are discussed in Chapter 4.

The first Portuguese settlements, based on trading fairs, had a limited area of jurisdiction which did not extend to the adjacent lands and people. There were generally no more than ten settlers at each fair and their presence would have been impossible without the agreement of the local African chief. Their position was, however, strengthened by the decline of the powerful Karanga empire of Mwene Mutapa from the end of the fifteenth century. North of the Zambezi, the expanding Malawi kingdoms did not reach their peak until the mid-seventeenth century but were, in part, responsible for limiting Portuguese penetration into such areas as Marávia until the late eighteenth century.

On a number of occasions the Portuguese authorities assembled armies with the intention of asserting their dominance in the Zambezi valley, the first being in 1571. Their almost invariable failure resulted from strong African resistance, inability to maintain adequate supplies, inappropriate equipment and the effects of diseases such as malaria (the valley earned a reputation for being one of the most unhealthy regions in Africa).

Military failure led to attempts to control the region by alternative means, principally through the *prazo* system. *Prazos* were parcels of land over which individual settlers were granted wide powers of jurisdiction on behalf of the crown. Although in some cases this was done with the agreement of African chiefs, large areas were forcibly expropriated. By the 1640s, almost the entire area of the south bank of the Zambezi, in a strip running from the delta 500 km upstream and extending up to 200 km in width, had been occupied in this way. *Prazo* holders were empowered to raise taxes and tributes from the Africans living on their land, exerting their authority by maintaining slave armies. The system back-fired on Portugal when *prazo* holders increasingly began to assert their independence and, in many cases, to assume characteristics similar to those of African chieftaincies. Newitt (1969) summarized the development and influence of the *prazo* system as follows:

> Historians are familiar with seeing African societies break up under the influence of prolonged contact with Europeans. On the Zambezi it was the European society which dissolved, while the African ... developed new institutions and a new type of organization which proved better able than almost any other African society to resist European imperialism. Europeans and Indians came to the Zambezi in the sixteenth and seventeenth centuries in search of land and gold. Their descendants, the *prazo* holders of the eighteenth and nineteenth centuries, became absorbed in the African population and provided dynasties of chiefs for new tribal groupings. (p67)

Histories of the Zambezi valley in the eighteenth and nineteenth centuries concentrate on the various attempts by Portugal to regain authority over the rebellious *prazos* and on the long and bitter feuds which occurred between the different *prazo* dynasties. It was this feuding which weakened their resistance and finally allowed Portugal to gain control in the early twentieth century.

The region of 'The Rivers', which comprised the Zambezi valley and the adjoining coastal plain, was established by the Portuguese, in 1635, and administered from Goa. In 1752, an administrative capital was established within the region, at Sena. Fifteen years later the capital was moved to Tete. The Administration's primary concern was the problem of controlling the *prazos* - a problem which became progressively more acute as fewer Europeans chose to settle in the region and existing *prazo* holders intermarried with Indian traders and African royal families. Proposals were made to stimulate renewed European settlement, for example in 1646, but were ineffective. It has been estimated that at no time before the twentieth century did the Portuguese population of the valley exceed a thousand; for much of the time it was considerably lower. Thus, concern to stimulate European settlement became a key feature in Portuguese plans to develop the region and remained so up to the time of Mozambique's independence.

Although gold was originally bought from African producers, during the eighteenth century mine operation by *prazo* holders became more common, especially in the area north of Tete. Female slaves were used to perform the mining operations. Similarly, ivory was bought, from independent hunters, but *prazo* holders frequently organized their own hunting expeditions. By the start of the nineteenth century, trade in both gold and ivory was in decline with accessible deposits of ore exhausted and elephant herds seriously depleted. It was at this point that the slave trade began to expand. It has been estimated that, at its peak, over ten thousand slaves a year were taken from the valley. Attempts to ban slave trading in the mid-nineteenth century provoked further resistance towards Portuguese authority from the *prazo* holders.

Agricultural production was, in general, of little economic importance on the *prazos* except in providing food for the *prazo* holder, his slaves and the African inhabitants. Cultivation was undertaken by the African population using traditional methods the main crops being sorghum, millet and maize[43]. The *prazo* holder levied taxes from the African 'residents' which were generally paid in the form of such produce.

Although new crops, such as sugar and coffee, were occasionally introduced many *prazo* holders preferred to import these commodities. In periods of famine, caused by drought or locust attack, staple foods were also imported.

Many observers believe that the Portuguese administration and the establishment of *prazos* in the Zambezi basin not only failed to increase agricultural production, before the last decade of the nineteenth century, but actually caused its decline. The extensive depopulation of the area produced by the slave trade, and by African migration to avoid the harsh conditions on many *prazos* or the effects of the increasingly bitter conflicts between *prazo* clans, had a considerable impact on rural production. For example, Ishemo (1978) suggests that, in the districts of Macanga, Angônia and Marávia, Africans were forced to flee from the fertile valleys which they had previously cultivated and to seek refuge in the much less fertile hills. Depopulation proceeded most rapidly during periods of harsh drought, such as that from 1823 to 1830, when many Africans were faced with the alternative of either dying of hunger or being taken into slavery.

Nevertheless, many Portuguese believed that the agricultural potential of the Zambezi valley was high although, according to Newitt (1969):

> only in the eighteenth century did the idea of increasing the population of the Zambezi become more closely associated with the idea of developing the area agriculturally. (p73)

Increasingly this idea became linked with that of establishing plantations so that:

> by the end of the nineteenth century most writers on Portuguese affairs assumed that *prazos* were intended to be plantations. (p74)

In the late nineteenth century plantations were established in the coastal region, around Quelimane, but elsewhere in the basin few successful plantation schemes were created. In a later work, Newitt (1973) argues that *prazo* holders had neither the resources nor the inclination to develop plantation agriculture and likens Portuguese hopes of agricultural wealth with their equally unrealistic hopes of mineral wealth:

> The *prazo*-holders could not have developed their estates into thriving plantations even had they wished, while the dreams of Eldorado in central Africa were totally unfounded - and were known to be unfounded ever since Vasco Homen found that the mines of Manica were only small river-side washings, and that the silver of Chicoa had no existence at all. Homen left the Zambezi in 1576, and from then until 1969, when the contracts for the building of Cabora Bassa dam were signed, there has never been any scheme for the economic development of the Zambezi valley which has had the slightest chance of success. (p153)

The widely publicized writings of European explorers and the thirst for imperial possessions by European powers awakened increasing interest in many parts of Africa, including the Zambezi basin, in the latter half of the nineteenth century. David Livingstone[44] became the most celebrated explorer in the English speaking world although it is now recognized that in many of his journeys he was preceded, by decades if not centuries, by Portuguese explorers. Livingstone was an outspoken critic of the life-style of the Portuguese settlers whom he met in the lower Zambezi, of the continuing slave trade and of the failure of the Portuguese Administration to achieve economic and social improvement in the region. Again, Livingstone was rarely breaking new ground. From time to time prominent Portuguese, including many inhabitants of the region, had expressed similar dismay at the lack of substantial development after three hundred years of colonial influence. For example, in 1827, during one of the severe droughts, eight citizens of Tete sent a report[45] to the Governor of Mozambique advocating:

a) abolition of the slave trade;

b) widening of the Zambezi river bed to promote trade;

c) making Quelimane into an international port;

d) creating public works to improve the prosperity of Africans;

e) setting up a properly staffed hospital in Tete for Africans;

f) building a new elementary school;

g) building a new municipal chamber;

h) building a new prison; and

i) arranging for the training of artisans and the establishment of workshops.

The authorities appear to have lacked both the resources and the inclination to invest in the region in this way. Interest in the mineral potential, however, persisted. For example, in 1857, the President of the Commission of Mines in Tete was asked to prepare a report on gold, iron and coal deposits in the Tete area for the Governor of 'Quelimane e Rios da Sena'[46].

For the present study, the most interesting parts of Livingstone's findings are those which concern the navigation potential of the lower Zambezi. Livingstone believed that navigation from the river's mouth would provide the basis for the establishment of British colonies on the Batoka Plateau (Zambia) where he intended to prove that 'enough sugar and cotton could be grown to make the area a commercial paradise'[47]. Neither he nor his government sponsors had acquainted themselves with the nature of the intervening rapids at Cabora Bassa Gorge, despite the fact that they had been reported as early as 1616, by the explorer Caspar Boccaro[48], nor had they asked themselves why, if the advantages of such a project seemed so obvious, the Portuguese settlers in the area had not established the proposed navigation link long before.

During his expedition of 1858 Livingstone discovered five serious obstacles to his plan to open the Zambezi to navigation:

(i) it took him almost three weeks to locate a navigable channel through which to enter the mouth of the river from the Indian Ocean;

(ii) his ocean steamer, the *Pearl*, could only penetrate the river for about 80 km;

(iii) his intention to chart a navigable channel along the river proved unrealistic when it was discovered:

> that shifting sandbanks altered all the channels dozens of times within a single year[49];

(iv) even his shallow steamer the *Ma-Robert*, which drew less than a metre, could not navigate certain stretches so that they:

> spent days aground on sandbanks while all of them sweated with winches and cables to get the *Ma Robert* off. Sometimes 150 miles (250 km)

from the sea the river was less than 2 feet (0.6 m) deep*[50];

(v) finally, having reached Cabora Bassa Gorge Livingstone discovered the true nature of the rapids and realised that even his suggestion of blasting a navigable channel was completely unrealistic.

Livingstone's attention then turned towards the Shire River and the highlands of present-day Malawi. He discovered that navigation up the Shire was easier than up the Zambezi, except that the steamer's paddles became choked with aquatic vegetation. Thereafter, until the Trans-Zambezia Railway bridge was completed in 1935, navigation along the Zambezi and Shire rivers became the principal means of access for the British settlers who followed Livingstone**.

Despite the difficult conditions, the trading network along the Zambezi was dependent on river navigation until well into the twentieth century. Until the end of the nineteenth century river transport was by canoes paddled by Africans although in places, notably at the delta and between Tete and Chicoa (past Cabora Bassa Gorge), teams of porters carried the goods by land. Following Livingstone's introduction of a steamer onto the Zambezi, the Portuguese began operating two steamers despite the fact that transport by canoe remained considerably easier.

Navigation through the delta region was a particular hazard because of the speed with which channels became choked with silt or with trees and other vegetation. In the period from the 1770s to the 1830s *prazo*

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* Livingstone made five trips from the mouth to Tete between May and November 1858. He was, therefore, experiencing the worst of the dry season conditions.

** The development of water resources in Malawi and, in particular, the hydroelectric development of the Middle Shire and the agricultural development of the lower Shire would form an interesting subject for further study. Livingstone, himself, had extravagent visions of how the region might be developed as Jeal (1973) records:

'As they steamed north, it was not long before Livingstone began to imagine rice, cotton and sugar-cane growing on the flat plains that extended for miles on both sides of the river. Soon he had even persuaded himself that the Shire's potential might be as great as the Nile's. But since the country was flat and has a tendency to flood, Livingstone had to admit that there was a fair chance that it would be unhealthy.' (p215) holders in the delta region were required, by the authorities, to use their slaves to maintain clear navigation channels but many failed to do so. The delta and lower river were also used by British boats following the establishment of settlers on the Shire highlands. The Portuguese attempted, in 1875 to establish a monopoly over navigation but were forced to withdraw, following British protests. The dispute subsequently became the subject of a treaty with Britain.

D J Rankin[51] was another British traveller who followed Livingstone to the Zambezi. In his journeys, which took him as far inland as the Luangwa basin, Rankin was impressed by what he believed to be the considerable commercial prospects of the region for agricultural and mineral production. In his attempts to stimulate the navigation necessary to develop this potential he discovered a hitherto little used channel in the delta which appeared to provide a substantial draught for boats and, in 1887, he established the port of Chinde at its mouth. Although the port prospered for five years, it declined subsequently because of heavy siltation of the channel.

It was, in part, the activities of such people as Livingstone, Rankin and the British settlers on the Shire which forced the Portuguese to give greater consideration to the economic development of the Zambezi basin. Later, Rhodes' imperial designs on central Africa, threatening to drive the Portuguese out of the region south of the Zambezi, increased the pressure on them to assert their presence. In the 'scramble for Africa' in the 1880s Portugal found itself in an extremely vulnerable position. The Portuguese claim over large areas of the Zambezi basin, including regions within present-day Zambia and Zimbabwe, was contested by stronger European powers. Ultimately, the international boundaries which were imposed at the 1888 Berlin Conference reflect the balance of political forces and interests at that time rather than a rational division of the region into geographically or economically defined units. Yet these boundaries remain a strong determining factor in the development of the region.

Attempts to reform the *prazo* system continued as the main pre-occupation of the Portuguese authorities throughout the nineteenth century. Following failure to achieve reform by legislation (the radical laws of 1854 being ineffectual) or by force (the military campaigns of the 1860s ending in disaster), Portugal eventually began to gain control by economic means. In the 1870s improvements were made to the port facilities at Quelimane and, thereafter, a new type of concession was introduced in which short-term leases were granted, on a commercial basis, over the *prazos* in Zambézia. This led to an expansion of plantation agriculture in that region. The first such concession, in 1874, was for growing poppies on a 20 000 ha *prazo* near Mopeia together with the granting of a monopoly over opium exports for a period of twelve years. The concession eventually fell under the control of J P Hornung, a British citizen of Hungarian descent, who changed to sugar production when the opium business failed and, in due course, established the Sena Sugar Estates*.

During the 1870s commercialization of non-plantation production also expanded, particularly in the region downstream of Lupata Gorge. Copra sesame and groundnuts became increasingly important as European demand for vegetable oils grew. A demand for wild rubber led to high levels of production for a short period in the 1880s. The level of production may be gauged by a report, by Rankin (1893), that, in 1892, 5 000 t of groundnuts and 200 t of sesame seeds were exported from the valley whilst, in 1891, 20 t of rubber was exported.

Rankin and Kerr (1886) reported a wide diversity of crops being grown in the valley although in the region upstream of Lupata Gorge they painted a picture of commercial stagnation and agricultural decline. The neglect of Tete Province continued well into the twentieth century, as information gathered by the MFPZ[52] from contemporary reports confirms. Almost the entire output was derived from peasant production. Newitt (1973,p365) cites evidence to suggest that, within Tete Province, the entire area under European cultivation in 1914 was only about 2 600 ha. The principal estates, in the Revúboè and Mavuzi basins, had been planted with such crops as sisal, coconut, rubber, kapok, sesame, groundnuts, potatoes, coffee, tobacco, citrus fruits and cassava, but there is no record of any significant

* The Mopeia plantation was irrigated, at first by ditches and later by iron pipes which carried water pumped from the river. This system largely overcame the problem of drought, which had previously affected plantation agriculture, but the land remained vulnerable to flood damage in wet, years (for example, 1889). This problem was later overcome by dike construction.

or sustained commercial output from these plantations.

By contrast, the plantations in Zambézia Province covered 25 000 ha by 1914 and were producing 10 000 t/yr of copra and 25 000 t/yr of sugar. These plantations continued to expand in the 1920s when sugar exports reached a sustained level of 70 000 t/yr. Their expansion was, however, dependent on obtaining an adequate and cheap supply of labour for which recruitment took place over a wide area, including large areas of Tete Province.

The first attempts to obtain labour for the new plantations of the delta region were confined to coercing the Africans living on the concession area to work within the plantation. The natural response of many was to flee. As a result plantation owners sought to acquire ever larger concession areas simply to provide labour for their existing plantations. The State became increasingly involved in the process of labour recruitment, at first by allowing Africans to provide labour *in leiu* of taxes and later by becoming more directly involved in the process of coercion. However, until the 1930s, Portugal was unable to provide direct administration for the whole of Mozambique and, as a result, introduced, for a period, a new type of regime based on a development of the system of indirect administration under the *prazos*. The new system involved granting wide powers of administration over large areas of the country to land companies supported largely by foreign capital.

The Mozambique Company, formed in 1888 and granted a charter in 1891, was given control over much of the present-day Manica and Sofala Provinces including the south bank of the Zambezi valley. Smaller companies, including the Campanhia do Boror, the Société du Madal, and the forerunners of the Sena Sugar Estates, were granted concessions in the richer lands of the coastal plain north of the river where they established, or continued, plantation production. The remaining lands north of the river, together with much of Tete Province, were controlled by the Campanhia da Zambézia. This company was established for speculative mineral prospecting and had little interest in agriculture beyond that of recruiting labour, from its concession area, for plantations elsewhere. Large areas were, however, offered as sub-concessions to other companies or individuals, some of whom undertook agriculatural production.

In the early twentieth century the plantation companies expanded rapidly. Boror established very large coconut plantations along the coast near Quelimane. Sena Sugar began production at Mopeia, Sena, Marromeu and Luabo although production ceased at the first two during the recession of the 1930s. Further inland a number of sisal and tea plantations were also established. Generally speaking, all these plantations had a low productivity in terms of both land and labour. Very little mechanization was used and the introduction of fertilizers or new crop varieties was rarely attempted. Even draught animals were not introduced on a large scale until the late 1930s.

Even in those concessions where plantation agriculture was practised, peasant production of food crops remained important. Surpluses were purchased to feed the plantation workers but, since the companies had a monopoly over commercial acitivites within their concession area, there was a tendency for them to impose low prices on producers and high prices on consumers with the result that production declined. Continuing African migration away from concession areas, and the introduction of forced cotton and rice production within many concessions after 1938, led to a further decline in peasant production of food. In this way, the Zambezi valley was increasingly transformed into a labour reserve not only for the plantations but also for mining and agricultural interests in South Africa and Rhodesia.

In 1930, with the establishment of Salazar's *Estado Novo* in Portugal, the State replaced the indirect administration of the land companies by direct administration over the whole of Mozambique for the first time. In the Zambezi valley this included a direct involvement in labour recruitment for the plantations. Newitt (1973) suggests that the system which was developed was more efficient and, therefore, less humane leading to increasingly harsh exploitation of African labour and, at the same time, producing a decline in economic activity and production. He concluded:

> Since 1930 there has probably been no more depressed and inert area of Africa than Zambesia, Barue and Sofala, and the great river is probably more silent now, more devoid of traffic and bustle than at any time for a thousand years. All may well be transformed by the building of the Cabora Bassa dam, but that is still in the future. (p376)

Statistics for agricultural production in the valley, which were collected as part of the MFPZ's investigations, provide an indication of the stagnant state of agriculture in the region throughout the whole period from 1930 to 1960. For example, in 1963, only about 2.3% of the basin area within Mozambique was included in forestry or agricultural concessions (363 concessions covering 330 x 10^3 ha)[53]. Of the area covered by concessions, 76% lay in Zambézia Province whilst only 7% lay in Tete and 17% in Manica/Sofala. Five large concessionaires accounted for 58% of the total area: the Zambézia, Sena Sugar, Madal and Boror companies together with Sr. R B P Lopes. Even within concession areas only a small proportion of the land was cultivated in any one year. Thus, in 1958, only about 13% of the total concession area was under cultivation: approximately 400 ha in Tete, 7 000 ha in Manica/Sofala and 31 000 ha in Zambézia[54]. Cotton production had expanded under the system of forced cultivation to reach a total of 87 000 t/yr in 1955[55], but the system, which was highly inefficient and inhumane, provoked such strong resistance from the African population that it was dropped in the 1960s.

Livestock, principally cattle and goats, were kept by the local people in parts of Tete and were reared commercially in the floodplain by a number of the plantation companies. The MFPZ[56] was extremely critical of indigenous stock rearing and claimed that serious over-stocking resulted. The number of cattle around the city of Tete in the early 1960s was reported to be about 60 000 and in Angola about 50 000. Elsewhere in the Tete Province tse-tse fly infestation limited cattle numbers.

In the years between 1930 and 1948 the Portuguese authorities did little to promote the economic development of the Zambezi valley; an inadequate transportation system remained one of the principal constraints. Consideration was given to the possibility of damming the gorge at Cabora Bassa and providing locks in order to improve downstream navigation and enable boats to reach the middle Zambezi*. In 1927, Sousa e Silva[57], suggested that such a dam could also generate hydroelectric power. Nevertheless, the authorities undertook no surveys or investigations either of a topographical or hydrological nature.

* See, for example, the 1911 edition of *Encyclopedia Britannica*.

Relatively large cargoes were transported at that time in the delta region and along the Shire but river transport on the Zambezi was slow and hazardous[58] with the result that the volumes transported upstream of Mutarara were small. For example, in 1908, vessels powered by steam or sail carried a total of only 1 000 t of cargo upstream to Tete, returning with approximately 300 t. By 1940, the combined upstream and downstream cargoes totalled about 8 000 t/yr[59] a large part of which presumably comprised the exports of coal from the mine at Moatize. Within ten years the completion of a rail link to Moatize largely displaced navigation upstream of the Shire confluence, although, as late as 1958, seven vessels were reported to be operating on this section of river (the largest had a capacity of 9 t and a draught of 0.55 m; and all but one were powered by sail).

The construction of the railway may, indeed, be regarded as an important economic development but it arose not from a Portuguese initiative but from the demands of British interests in Nyasaland (Malawi). In 1922, a line had been constructed from Beira to Sena with the intention of transporting goods from the rail head by boat to Port Herald (Chiromo). This became increasingly difficult as a result of progressive siltation of the Shire. Attempts were made to resolve the difficulties by extending the Nyasaland railway downstream but problems were still encountered until the river link was eliminated by building a bridge over the Zambezi, at Mutarara, in 1935*. The Sena Sugar Estates quickly took advantage of the link between Beira and Sena by constructing a line from Sena to Marromeu and aqreeing to transport all the sugar from that factory by rail in return for very favourable rates. It was not until 1950, however, that the Portuguese authorities took advantage of the Mutarara bridge by building the line along the north bank of the river to Moatize. No new lines have been constructed since 1950 apart from an improved route to Marromeu from Inhaminga.

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* It would have been more logical to have built the railway from Quelimane rather than Beira in the first place but, at the time, Britain feared a collapse of Portuguese authority in Mozambique and under an earlier agreement between Britain and Germany the northern half of Mozambique, including the port of Quelimane, would have fallen under German control.

The development of the basin upstream of Cabora Bassa

Before proceeding to a discussion of more recent developments in the Zambezi basin within Mozambique it is necessary to study, in rather less detail, the historical origins and principal characteristics of river regulation works upstream. The Kariba and Kafue Projects, discussed in a separate section below, provide the only reservoir storage at present capable of exerting an appreciable degree of direct influence over the inflows to Lake Cabora Bassa. Nevertheless, a more general description of water resources development in Zambia and Zimbabwe is included so as to set the present study within the broader context of river regulation and development in the basin as a whole.

It is only during the last hundred years that European settlers have had a significant influence in the Zambezi basin, upstream of Cabora Bassa. Prior to this over much of the region, where population densities were relatively low, the inhabitants largely depended on shifting agriculture supplemented by hunting, gathering and fishing[60]. In the floodplains of the major rivers, higher population densities were supported through the cultivation of permanent or semi-permanent gardens close to the river. Cattle were also kept in certain regions, particularly around the Kafue Flats, where the annual cycle of flooding provided large areas of grassland which supported the large herds through the dry winter months. Floodplains, such as the Kafue Flats and Lukanga Swamps, were also rich fishing grounds. Fishing continues to provide an important source of protein in Zambia; in many areas fish is eaten in far greater quantities than meat.

During, and prior to, the nineteenth century individual explorers, hunters and missionaries had penetrated the upper basin from both the east and west coasts, but the routes did not afford ready access for permanent settlement. Thus, it was not until Cecil Rhodes, and his companions of the British South Africa Company, began forcing their way north through the region of Zimbabwe that the upper basin was finally opened to exploitation by European settlers. Coming from the south, they encountered the Zambezi as an obstacle to their easy penetration of the region north of the river. It was for this reason that the river was eventually chosen as an inter-territorial boundary. Had navigation along the river been the initial means of access to the region partition in this way would have been extremely unlikely.

The first bridge over the Zambezi was built in 1904 in a location, chosen by Rhodes, to give a commanding view of the Victoria Falls. It had been intended to incorporate this in the proposed Cape to Cairo railway. The other major crossing point at that time was at Chirundo where a ferry existed for passengers and, later, vehicles. This was replaced by a road bridge in the 1940s. Navigation along the river was attempted by a number of explorers in the nineteenth and twentieth centuries but, despite repeated suggestions that commercial navigation could be developed, the waterway was never used[61]. This resulted, in part, from a British preference for developing communication links with South Africa but, more importantly, from the realization that developing the Zambezi as a transport route would be both difficult and expensive because of the rapids at Cabora Bassa and Kariba Gorges and the shallow sandy reaches in the Mozambican plain. Upstream of the Victoria Falls attempts were also made to develop navigation but, here too, the maintenance of a transport route would have been too expensive relative to the likely volume of traffic[62].

The first proposals for major water engineering works concerned the hydroelectric power potential of the Victoria Falls. At the time these plans were conceived, the power demand of the newly developed mines in Zimbabwe was relatively modest and the minerals of Zambia lay unexploited. In consequence, there was no local demand for energy comparable with the potential supply. It was proposed, therefore, that the electrical energy would be transmitted to the Transvaal to meet the rapidly increasing demand of the gold mines. As early as 1905, Esson wrote:

> The utilization of the Victoria Falls for the purpose of transmitting power electrically to the Rand is no new scheme, though only recently has it been brought prominently before the public[63].

It is interesting to note the similarity between this early proposal for hydroelectric development in the Zambezi basin and the eventual Cabora Bassa Project. Both incorporated transmission lines of exceptional length designed to carry virtually all of the generated output to the Transvaal. The Victoria Falls Scheme had twin transmission lines 1 100 km long carrying three phase alternating current at a phase voltage of 60 kV with an extremely low frequency, either 3.5 or 7 Hz[64]. Each line could have carried the full load should the other have been unavailable. The initial installed capacity of the project was to have been 22.5 MW, very modest by present standards.

The project sparked off considerable controversy in the technical press. For example, it was argued, by Hammond (1905), on the basis of Esson's calculation of capital costs together with an assumed value for total line and transformer losses of 33%, that thermal power generation located at the head of coal mines in the Transvaal would have considerable economic advantage. Nevertheless, the supporters of the Victoria Falls Scheme managed to maintain interest in the proposal and to attract speculative capital. As a result, in 1906, they were able to launch a company with monopoly rights to power generation at the Victoria Falls - The Victoria Falls and Transvaal Power Company. Although, not surprisingly, the original scheme was never implemented, the rights granted to operate as an electrical power utility in the Transvaal enabled the company to gain a foothold and to begin supplying the mines with power from local coal-fired stations. From this beginning it developed to become the largest and most lucrative private power utility in the RSA. It was finally incorporated within the national electricity supply organization, Escom, in 1948.

Meanwhile the power potential of the Victoria Falls was neglected by the company. In fact, when, in 1906, a source of electrical power was sought for the nearby town of Livingstone (which served as the administrative capital of Northern Rhodesia from 1889 to 1924) a small thermal generating unit was installed.

Southern Rhodesia's public and industrial supply of electrical energy was based, almost exclusively on thermal generation from the time of the earliest installations until 1959. The substantial reserves of coal, at Wankie, which became the principal source of fuel for this supply were also used to provide power for the initial exploitation of minerals at the Broken Hill mines of Northern Rhodesia. In 1925, however, a dam was constructed above a gorge on the Mulungushi River (a tributary of the Luangwa) and a 2 MW hydroelectric generator was installed[65]. Subsequent additions, in 1927 and 1945, brought the scheme's total installed capacity to 20.6 MW. In 1945, the mining company began a new project on the nearby Lunsemfwa River. Initially, this was a run-of-river project with an installed capacity of 12 MW but, with completion of the Mita Falls Dam in 1958, reservoir storage was provided which allowed the installed capacity to be increased to 18 MW. Nevertheless, the power demand of the Broken Hill mines was small compared with that of the copper mines which were rapidly expanding in the northern part of the Kafue catchment. Because of their distance form the Victoria Falls (500 km) it was initially considered more economical to import coal by rail from Wankie to the Copperbelt, than to use hydroelectric power. At a later stage this decision had important political and economic repercussions when the Copperbelt began to suffer power shortages as a result of difficulties in hauling an adequate supply of coal along the congested railway line.

The installation of the first hydroelectric generators at the Victoria Falls was completed in 1938. The project was a simple run-of-river scheme, of 2 MW, designed solely to meet the growing demand around Livingstone. The station's installed capacity was increased in stages and reached 8 MW by 1955. With the construction of the CAPC high voltage transmission network, to carry power from Kariba, it became feasible for the first time to connect the Victoria Falls to the areas of heavy energy demand in the Zambian Copperbelt and in Zimbabwe. A second run-of-river power station was built in 1969, with six 10 MW generating sets, and a third was added in 1972, (with four 10 MW sets)[66]. The Victoria Falls schemes have been operated throughout by the authorities in Zambia; there has been no power development on the Zimbabwean side of the falls. The present installed capacity is thought to be the maximum which could be justified for a run-of-river project. Proposals have been made, at various times, to provide upstream storage so that the firm power potential might be increased. However, there are few suitable sites for dams. Furthermore, any reservoirs which could be formed would have large surface areas and be relatively shallow and would, therefore, suffer large evaporation losses. The social and environmental implications of such projects are also significant (see Chapter 6).

Upstream of Cabora Bassa large-scale hydroelectric installations are feasible only on the main Zambezi and on the Kafue. Nevertheless, Increase in reservoir capacity in Zimbabwe 1958-1973

Source: Olivier, *Great Dams*

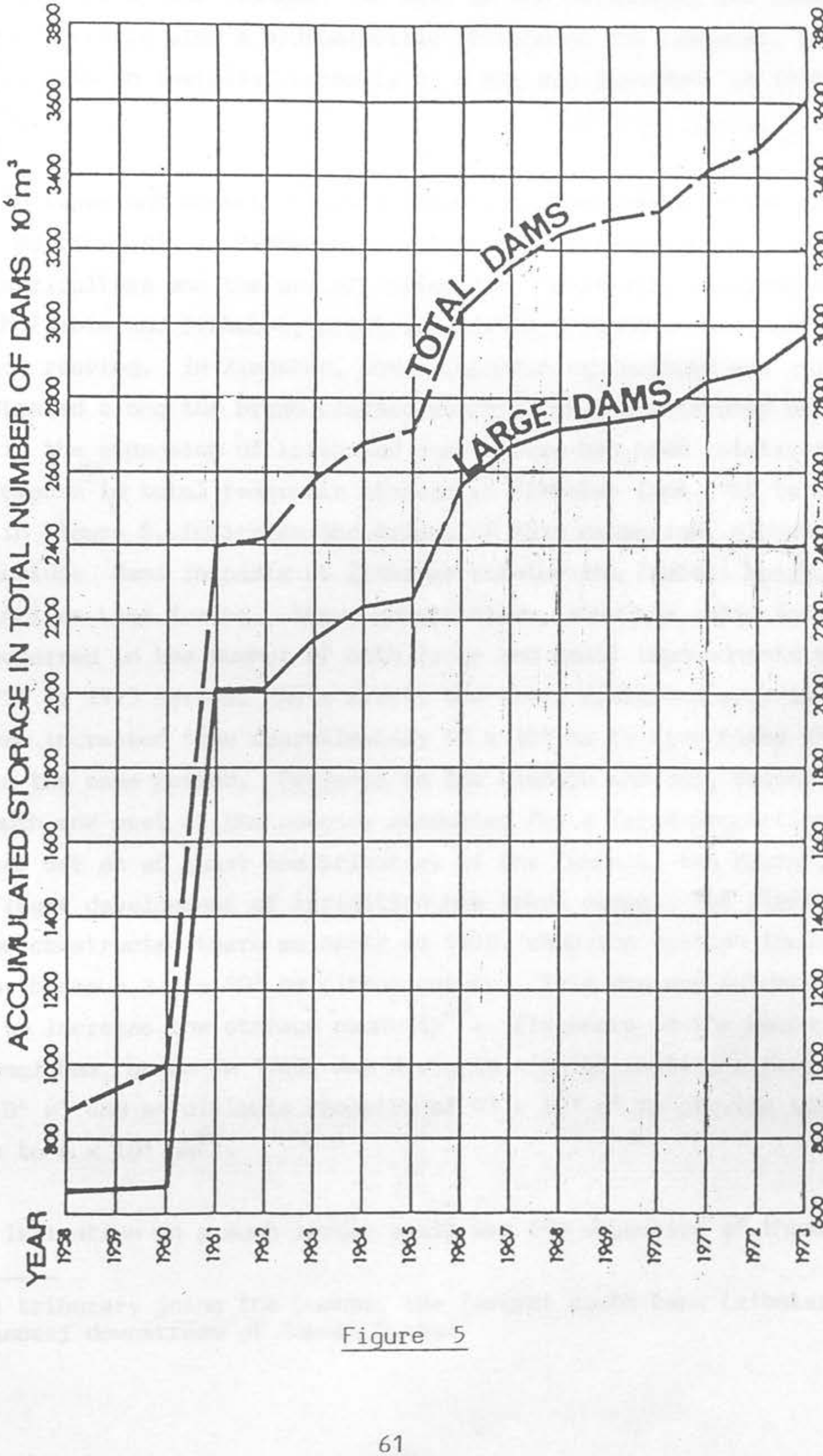


Figure 5

some suitable sites exist for smaller projects on tributary rivers; such as those on the Mulungushi and Lunsemfwa rivers described above. In Zimbabwe there are a number of small private and industrial generators in operation on tributaries of the Zambezi but their individual capacity is generally below 1 MW. In Zambia, the most suitable sites are those on tributaries of the Luangwa. As well as the Mulungushi and Lunsemfwa projects there is also a hydroelectric station on the Lusiwasi, built in 1971, with an installed capacity of 6 MW; and expanded, in 1974, to 12 MW.

An important aspect of water resources development in the Zambezi basin, particularly in Zimbabwe, has been the introduction of European style agriculture and the use of irrigation. Initially European settlers, in both Zambia and Zimbabwe, practised either dryland arable cultivation or stock rearing. In Zimbabwe, where European agriculture was initially concentrated along the broad plateau which marks the watershed of the Zambezi, the expansion of irrigated agriculture has been relatively recent. The increase in total reservoir storage in Zimbabwe from 1958 to 1973, shown in Figure 5, indicates the extent of this expansion, although the data include dams in parts of Zimbabwe outside the Zambezi basin, and also include Lake Kariba. They, nevertheless, show the rapid increase that occurred in the number of both large and small impoundments during the 1958 to 1973 period. As a result the total irrigated area in Zimbabwe increased from approximately 10×10^3 ha to five times that area in the same period. Projects in the Limpopo and Sabi basins, in the south and east of the country accounted for a large proportion of this increase but on at least one tributary of the Zambezi, the Mazoe*, significant development of irrigation has taken place. The first large dam was constructed there as early as 1918, when the British South Africa Company began a 2.4×10^3 ha citrus estate. This dam was heightened, in 1961, to increase the storage capacity[67]. Elsewhere in the Mazoe basin the Wengi Dam, begun in 1968, was designed with an initial capacity of 12×10^6 m³ and an ultimate capacity of 43×10^6 m³ to provide irrigation for up to 4×10^3 ha[68].

Irrigation on a much larger scale was the objective of those who

* This triburary joins the Luenha, the largest south bank tributary of the Zambezi downstream of Cabora Bassa.

proposed one of the earliest schemes to regulate the Zambezi. The proposals, which were based on major surveys undertaken in 1925 and 1945, entailed a major diversion to the south of water from the Zambezi upstream of the Victoria Falls in order to irrigate the Okovango Delta in Botswana. Following the decision to build the Kariba Dam it was concluded that the hydrological requirements of the Kariba Project would not allow such a diversion to be made. Nevertheless, Wellington (1950) reassessed the previous reports and concluded that, even without water from the Zambezi, it would be possible to irriagte 800 x 10^3 ha of former swamps; although he did not discuss the possible environmental effects of such a scheme. He supported the view of a former colonial official that the Okovango Delta was 'a potential Egypt in Southern Africa'.

Phrases such as 'the breadbasket of Africa' occurred frequently in the writings of Wellington's contemporaries as they studied the Zambezi basin. Two areas to which this phrase was particularly applied were the Barotse Plain and the Kafue Flats, both of which are extensive, seasonally inundated, floodplains in Zambia. Of the two, the agricultural development of the Kafue Flats is under more active consideration at present. In either case, however, the far-reaching hydrological and environmental changes which would result from implementing such proposals will have to be carefully considered if the overall result is to be wholly beneficial.

Water extraction for industrial and municipal consumption is not a major factor in the management of water resources in most parts of the Zambezi basin. Groundwater is used extensively in both Zimbabwe and Zambia and, even where surface water is used, the quantities are relatively small. For example, part of Lusaka's supply is carried from the Kafue along a 60 km pipeline which has a capacity of 90 x 10^3 m^3/day (33 x 10^6 m^3/yr)[69]. Kitwe draws slightly greater quantities from the Kafue. But together these two cities consume less than 1% of the river's mean annual discharge. The largest reservoir for municipal supply in the Zambezi basin is at Darwendale, on the Hunyani tributary in Zimbabwe. This reservoir, which is one of five built to supplement the original groundwater supplies to Harare, has a capacity of 490 x 10^6 m^3[70].

Other changes in the catchment of the Zambezi have had important effects on its runoff characteristics and on the transport of sediment. These include processes such as the replacement of natural vegetation by European agriculture, the felling of trees for timber and the increase in population densities around urban centres and in certain rural areas such as the 'tribal lands' to which the local people were displaced by settlers. The implications of such changes for the management of water resources downstream are discussed in later parts of the thesis (see Chapter 5 and Appendix 6).

The Kariba and Kafue Projects

Proposals for engineering works in Kariba Gorge were first put forward at the end of the nineteenth century although its hydroelectric potential was not formally considered until 1925. The principal investigations and proposals for projects in the gorge may be summarized as follows[71]:

1891: a survey of the gorge by W K Steer who reconnoitred the route for a possible railway crossing;

1898: Sir Charles Metcalfe considered bridging the Zambezi at Kariba to take the Cape to Cairo railway;

1912: a report by H S Keigwin, who considered that the country offered attractive irrigation possibilities;

1914: the flow of the Zambezi was measured at Kariba to determine the irrigation potential of the area;

1925: the comprehensive study entitled 'Water Power Resources in Southern Rhodesia' prepared by the Hydrographic Engineer of the Southern Rhodesia Government considered the power potential at Kariba and Mpata gorges as well as at the Victoria Falls;

1927: a report by P H Haviland to the Rhodesia Base Metals Syndicate on possible hydroelectric development at Kariba (His opening remarks stated that, with the amount of power available at the Victoria Falls, power production at Kariba need not be considered);

1937: a South African periodical suggested that a hydroelectric dam, 60 m high, at Kariba was capable of revolutionizing the economies of Northern and Southern Rhodesia; and

1941: investigations by the Electricity Supply Commission of Southern Rhodesia at the Kariba Gorge for power development, including survey work in the gorge until 1944.

Despite this long history of interest in Kariba Gorge there had been very little systematic survey work carried out before 1941. This was largely because of the remote location of the gorge and its position on the inter-territorial boundary. Moreover, there were no hydrological stations on this section of the Zambezi until 1943 when gauge records were begun at Chirundu, downstream of the gorge[72]. No gauge was established in the gorge itself until 1949.

In the 1940s the proposed project at Kariba became the centre of increasing political controversy. In 1945, the British Government set up a co-ordinating body, the Central African Council, which became the forerunner of the Federation which was later established between the colony of Southern Rhodesia and the protectorates of Northern Rhodesia and Nyasaland. This council, in 1946, appointed an Inter-Territorial Hydro-Electric Power Commission:

> to study the possibilities of the Kariba and Kafue hydro-electric power projects and any other large sources of power available for joint development[73].

A bitter debate was soon underway over the relative merits of the Kariba and Kafue Projects; a debate which closely reflected the attitudes of politicians from different parts of the region to the whole idea of a Central African Federation.

Despite its broad terms of reference, politicians in Southern Rhodesia regarded the Hydro-Electric Commission solely as an instrument through which the Kariba Project could be implemented. Their aim was to build, within ten years, a dam at Kariba; this was considered to be the only site, wholly or partly within their territory, which could produce sufficient energy to meet their predicted demand over the next twenty years and, thereby, avoid further investment in thermal plant. They wished to avoid an expansion of thermal generation in order to conserve their coal deposits for metallurgical processing and to prevent further congestion on the railway network which transported the coal to the power stations. However, it was not possible for Southern Rhodesia to proceed with the Kariba Project by itself because the reservoir would flood parts of Northern Rhodesia; because the cost would have been too high for one territory to have borne by itself; and because the predicted energy demand in Southern Rhodesia, although increasing rapidly, would not have been high enough to justify the building of a hydroelectric project of Kariba'a size.

By contrast, the authorities in Northern Rhodesia were not interested in co-operating in the construction of Kariba Dam but were interested solely in the Kafue Project. Their arguments were that the Copperbelt needed power as soon as possible (the proposed Kafue Project could begin generating sooner than that at Kariba), that the Kafue Project would require a smaller financial investment and might even prove to be cheaper per unit output, that its site was more accessible and would require shorter electrical transmission lines, that the Kafue basin also offered the possibility of large-scale irrigation development, and, finally and of considerable importance, that the Kafue Project would be located wholly within Northern Rhodesia and would enable the territory to achieve greater economic independence from Southern Rhodesia than had hitherto been possible.

In purely technical terms the Kafue Project seemed, at first, to be preferable. The technology required - tunnels and pipes leading water from a small diversion dam to a surface power station further down the gorge - was well developed whereas few dams of the size proposed for Kariba had been constructed at that time. Hydrological records had been kept over a long period at a point close to Kafue Gorge whereas no records of adequate length were available for a site close to Kariba Gorge, hydrological calculations for this project being based on records at the Victoria Falls. In addition, the Kafue Project involved no major impoundment whereas a large displacement of population would be caused by the reservoir created by the Kariba Dam. However, the creation of this reservoir was an important factor in Kariba's favour since the storage capacity it provided would make the calculations of guaranteed power output less dependent on values for the minimum discharges of the river and, therefore, less vulnerable to poor hydrological forecasts arising from the inadequacy of the available data.

The debate reached its height in the early 1950s as the following summary of events indicates[74]:
December 1950: a report on the Kariba Project, prepared by a team of

consulting engineers appointed by the Inter-Territorial Commission, recommended that the Kariba Dam should be built because the hydrological and topographical information for the Kafue Project were considered to be inadequate and because forecasts of electricity demand indicated that Kafue could only provide a short-term solution to energy requirements;

October 1951: the authorities in Northern Rhodesia instructed the same consultants to prepare a report investigating the possibility of a smaller scheme (200 MW) on the Kafue to be completed as soon as possible, but allowing for extension and integration into a Federal power network at a later date;

1952: temporary arrangements were negotiated between the mining companies on the Copperbelt and the Union Minière du Haut Katanga to import energy from La Marinel hydroelectric scheme on the Lualaba River (at least 450 GWh/yr with a maximum power of 50 MW to be made available for a minimum of five years from 1957);

29 January 1953: the report from the consultants on the amended Kafue Project indicated that its energy would initially be cheaper than that from Kariba but that the latter would be cheaper once its ultimate capacity was reached (it was also suggested that the first stage hydrological potential at Kafue Gorge in the driest year had been over estimated and should be reduced to 186 MW at 80% load factor);

7 September 1953: the authorities in Northern Rhodesia with the full support of the mining companies including the Anglo-American Corporation, allocated £1 million for preliminary civil and geological works at Kafue on the understanding that the Federal Government would continue the project after the passing of the Act of Federation later in the same year;

March 1954: in a debate on the Hydro-Electric Power Bill in the newly created Federal Parliament, Prime Minister Huggins contradicted an earlier assurance by his Minister of Commerce and Industry and asserted that promises made by the Northern Rhodesians to finance Kafue could no longer be fulfilled since finance could only be made available through the Federal Government;

June 1954: Sir William Halcrow, one of the original consultants, made a speech in which he argued that both Kariba and Kafue should be built but that the argument for Kafue to be built first, based on the urgent need for power in the Copperbelt, had been weakened by the

Katanga power deal;

28 June 1954: Huggins announced that the World Bank was prepared to provide a loan but that revised reports on the two projects would first be prepared by a team of French experts - these reports were published three months later and André Coyne was invited to help evaluate them;

January 1955: Coyne advised whole-hearted support for the Kariba Project, which required an arch dam of the type developed by Coyne and on which he was later to be appointed chief design consultant, and suggested a means to accelerate the construction programme for the Kariba Dam;

March 1955: the Kariba Project was formally approved by the Federal Government, with power to be available by 1960, although negotations about finance had not been completed;

July 1955: the World Bank, which had previously refused to undertake its own assessment of the relative merits of the two projects, announced its decision to provide finance for the Kariba Project and formalized the agreement in January 1956 with a loan of an unspecified amount;

1956: a bitter debate took place in the Federal parliament in which back-bench members from Northern Rhodesia, annoyed both by the rejection of the Kafue Project and the decision to site the first stage power station on the south bank at Kariba, called for work at Kariba to be stopped (there were also protest meetings in Lusaka and a petition was sent to the Queen); and

December 1958: the impounding of Lake Kariba began.

A summary of the technical details of the Kariba Project may be found in Appendix 1. Full details may be found in the references[75]. Other aspects of the project, including its hydrological and siltation characteristics and its social and environmental effects, are discussed in later chapters of this thesis.

A federal power authority, which later became the Central African Power Corporation (CAPC), was established to operate the 600 MW* project and the associated high voltage transmission network. This arrangement was continued despite the break-up of the Federation in 1963, the independence of Zambia in 1964 and the UDI declaration by the white minority in Southern Rhodesia in 1966. Within a year of UDI, the Zambian

* The installed capacity of the South Bank Power Station was later uprated by over 10%.

authorities, fearing that their power supplies might be endangered, since neither the control centre for the power station nor that for the transmission network were within Zambia, obtained financial support from the World Bank for a resumption of work on the Kafue Project; the Bank refused to support Zambia's alternative proposal to build the North Bank Station at Kariba. Even before this, interest in the Kafue Project had continued despite the construction of the Kariba Dam. In 1962, a team formed under the FAO began work on a multi-purpose survey of the entire Kafue basin. The findings were published as a seven volume report in 1968. By then, construction had begun on the first stage of the project; the building of a 50 m high dam in the gorge which would create a small storage reservoir as well as diverting water into the headrace canal and penstocks of the power station. Unlike the plans proposed for the earlier scheme, the power station, with an installed capacity of 600 MW, was not built on the surface but at a considerable depth within the mountain on the south bank of the gorge.

For a summary of the technical details of the Kafue Project see Appendix 1. Full details may be seen in the references[76]. The environmental impact of the Kafue Project and the conflicts which have arisen over possible multiple purpose utilization of the basin's hydrological resources are referred to in later chapters of this thesis.

The reservoir at Kafue Gorge could not provide sufficient storage capacity to maintain the required output throughout dry years, even when its water level was allowed to rise so high that prolonged, and ecologically harmful, flooding occurred over vast areas of the Kafue Flats. A second dam was, therefore, constructed between 1973 and 1976 at Itezhitezhi Gorge, upstream of the Kafue Flats, to provide additional storage capacity. This second phase of the Kafue Project may also incorporate a 50 MW power station in due course. A third stage to the project has been proposed, involving the construction of a power station lower down Kafue Gorge to utilize the remaining 200 m of head and thus provide a further 300 MW.

The Zambian authorities expanded their country's electrical generating capacity extremely rapidly during the first decade of Zambia's independence. Apart from the Kafue Project they built two new power stations at Victoria

Falls, between 1969 and 1972, with a combined capacity of 100 MW. Furthermore, in 1971, work commenced on the delayed North Bank Power Station at Kariba. Although the construction period was prolonged, by rock falls in the underground machine hall and the subsequent liquidation of the principal civil engineering contractor[77], a further 600 MW was added to the capacity of the Zambian network by 1977. In the period from 1964 to 1977, Zambia moved from being a net importer of electrical energy, consuming considerably more than its allocated half share of the output from the Kariba Project, to being a net exporter. For example, in the year ended June 1977, despite the political tensions between the two countries, Zambia exported to Rhodesia over 45% of the energy consumed in that country. In effect, the energy exported comprised not only the whole of Zambia's share of the output from the two stations at Kariba but also a contribution from Zambia's other hydroelectric sources[78].

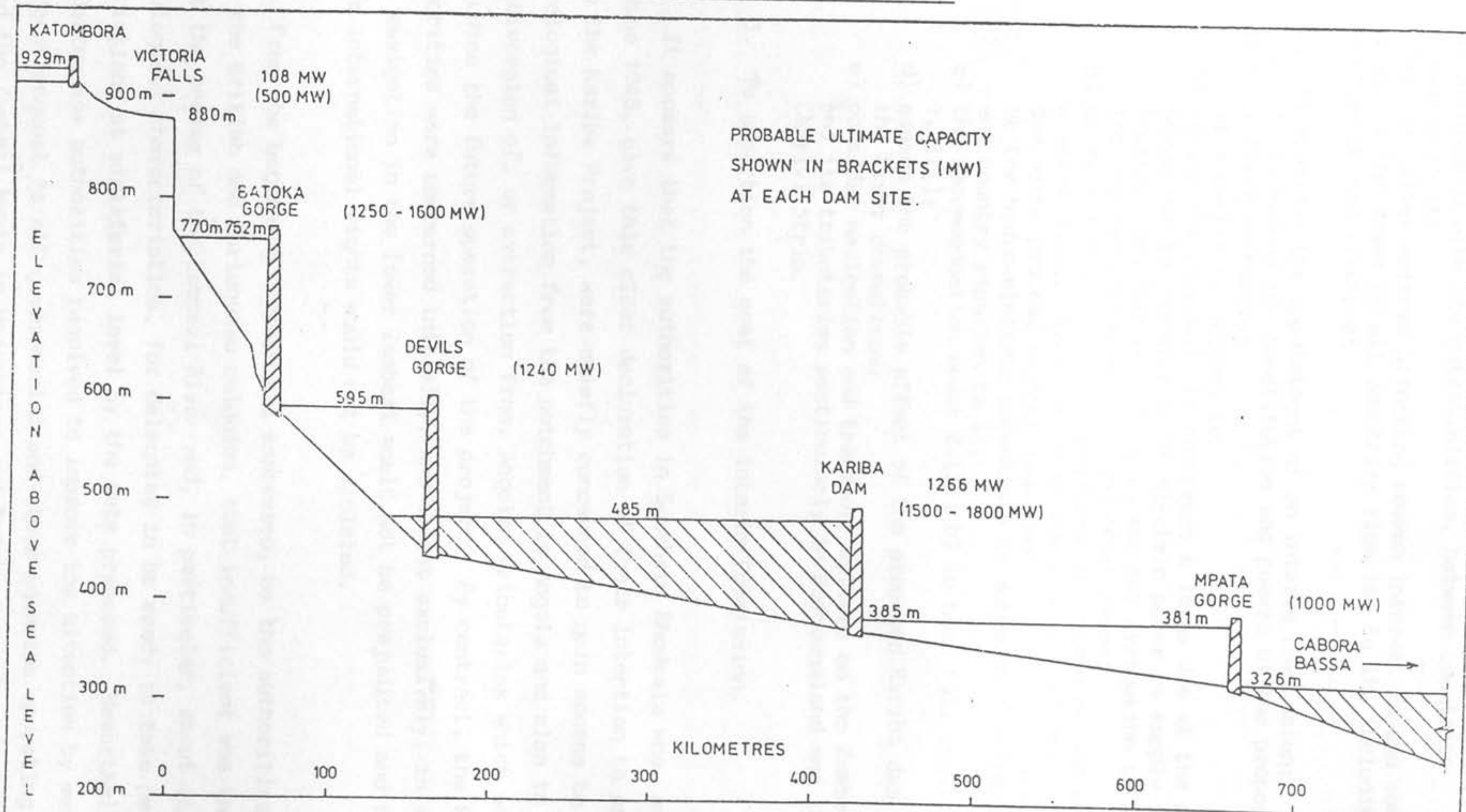
The authorities in Zimbabwe, both before and after its independence in 1980, have been concerned about this dependence on imported energy. Although interest has been focussed primarily on projects for thermal power generation at Wankie, investigations are being undertaken into the possibility of installing a further 300 MW at Kariba and of building additional dams on the Zambezi at Batoka and Devil's Gorges, upstream of Kariba, and Mpata Gorge, downstream of Kariba. Full details of these projects have not been published but their locations and approximate capacities may be seen in Figure 6. Further discussion of the electrical power situation in Zimbabwe may be found in Chapter 4.

The Zambezi Conference

In June 1948 the Portuguese authorities were invited to send representatives from Mozambique and Angola to an inter-governmental conference to take place in October of that year in Salisbury (Harare)[79]. The conference was to have the following agenda[80]:

> 1. To consider the establishment of a Zambezi River Authority having *inter alia* the following functions:
> (i) the continuous accumulation of all hydrographical and hydrological information pertaining to the River from its source and tributaries to its final discharge in the Indian Ocean;
> (ii) the determination and initiation of measures necessary to preserve and improve the flow of the River and its general conditions;

Figure 6: Proposed hydroelectric developments upstream of Cabora Bassa



Source: G F Allison, Address to Int. Economic Resources Conf., Zimbabwe, Sep. 1980.

(iii) the equitable appointment of the waters of the River, in accordance with its potentialities, between countries riparian to it;

(iv) all other matters affecting common interest in and common usage of the River by all countries riparian to it, including navigation and transport.

2. To consider the appointment of an interim commission:

(i) to recommend the constitution and powers of the proposed Zambezi River Authority;

(ii) as a matter of urgency to:

a) review the proposals to construct a large dam at the Kariba Gorge for the generation of electric power to supply Northern and Southern Rhodesia and for irrigation of lands for the production of food and other crops;

b) carry out necessary investigations to determine and recommend a water quality basis on which construction of the Kariba dam might proceed without impairment of or embarrassment to the hydro-electric potentials by subsequent action of any country riparian to it;

c) the recommendation under 2.(ii) b) to have full regard to 1.(iii);

d) assess the probable effect of the proposed Kariba dam on the River downstream;

e) consider navigation and transport matters on the Zambezi and its tributaries particularly in Bechuanaland and the Caprivi Strip.

3. To apportion the cost of the Interim Commission.

It appears that the authorities in Southern Rhodesia who, as early as June 1948, gave this clear declaration of their intention to proceed with the Kariba Project, were chiefly concerned to gain access to hydrological information from the catchment in Angola and also to prevent any diversion of, or extraction from, Angolan tributaries which would prejudice the future operation of the project. By contrast, the Portuguese authorities were concerned initially, and almost exclusively, in ensuring that navigation in the lower Zambezi would not be prejudiced and that their international rights would not be violated.

From the beginning concern was expressed, by the authorities in both the British and Portuguese colonies, that insufficient was known about the regime of the Zambezi River and, in particular, about its hydrological characteristics, for delegates to be ready to take part in negotiations at ministerial level by the date proposed. Nevertheless, the Portuguese authorities resolved to improve the situation by making an urgent request to all governmental and other agencies operating in or around the Zambezi basin in Mozambique and Angola for relevant information.

This, almost certainly, marked the first occasion on which an attempt was made by the Portuguese authorities to gather comprehensive information about the development of the Zambezi. Certainly the documents sent in response to the request indicate a profound ignorance about many of the more important physical, environmental and economic characteristics of the basin. In particular, it became clear that almost nothing was known at the time about its hydrology.

The documents were assembled by the Director General of Public Works and Communications and circulated, as Proceedings 261-5-2, under the title *Conferência do Zambeze. Resumo do processo e observações: Documentos* (August 1948 to 23 July 1951)*. By the date originally suggested for the conference thirteen short documents had been received of which five concerned navigation and one discussed agricultural potential. The only hydrological information was a record of annual maximum river levels at Luabo received from the Sena Sugar Estates. The two bibliographic contributions listed twenty-two relevant reports of which nineteen concerned geology (eleven for Angola) and three concerned navigation around Chinde.

It is by no means certain that the British authorities were any better informed about many of the relevant issues. At the end of October, 1948, they announced a postponement of the conference:

> because of the lack of certain technical information especially about the effects on the Lower Zambezi[81].

Later, it was proposed that a technical team from Southern Rhodesia should meet a similar team from Mozambique to discuss these issues. The conference proposal, in this way, became transformed from inter-governmental to technical negotiations. The reason for this change may, in part, have been the serious misgivings expressed by certain Portuguese officials about the political implications of a Zambezi River Authority and the possible loss of sovereignty which its creation might entail.

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* Herein referred to as *Conferência do Zambeze*. A copy of these documents was consulted by the writer in the offices of the SPA in Tete.

The date of the conference of technical personnel was finally arranged for the end of May, 1950. This delay provided the delegations with a further year-and-a-half to assemble relevant information. The Chief Inspector of Public Works in Portugal, Castro Cabrita, became increasingly involved in these preparations and finally led the Portuguese delegation. In August, 1949, he proposed the establishment of a hydrological network in the lower Zambezi basin comprising at least two discharge gauging stations on the main Zambezi and one each on the Shire and Luenha rivers. He also proposed sediment sampling at the same sections and a topographical survey to establish accurate levels from Quelimane to Zumbo. His proposals were adopted, apart from that of undertaking regular sediment sampling, and, as a result, the first official river gauges were established in the lower Zambezi valley and the first accurate profile of the river obtained[82]. Meanwhile, a certain amount of climatic and other information was obtained from Angola[83] and, in addition, a detailed description of the lower Zambezi River was submitted by Frederico Cruz, a former Captain of the Port of Chinde[84]. Cruz concluded that the Zambezi provided the basis for a very good means of communication which could be developed relatively easily to serve the vast rich international hinterland. He also suggested that the Port of Chinde should be developed but that the channel to Quelimane could be opened up at least as an outlet during the flood season. In addition, Cruz supported the idea of creating a special mission to undertake the necessary studies.

Formal invitations to the conference were issued to the authorities, in both Mozambique and Angola, but, in a revealing communication, President Salazar[85] stated that he had been informed by the Governor General of Mozambique that neither Mozambique nor Angola had experts who were competent to undertake such negotations and that they would have to be provided from Lisbon. By contrast, the British delegation did not draw on any expertise from London (see Appendix 2).

After Cabrita took charge of the Portuguese delegation he became increasingly frustrated with the lack of adequate information. Two months before the conference, he wrote to the Director General of Colonial Development complaining that the information he had so far received gave little basis upon which to formulate opinion[86]. Nevertheless, he had already begun to take a keen interest in the Zambezi valley. He circulated, to officials in Lisbon, copies of a paper, *Aproveitamentos de fins múltiplos**, in which he argued the benefits of multiple purpose river development. His opinions on this subject left their mark not only on the conference but on the subsequent Portuguese interest in developing the resources of the Zambezi basin.

It is clear that before his involvement in the conference Cabrita had apparently had little experience of the Zambezi. In 1948, therefore, he flew from its mouth to Zumbo and later helped to determine the dry season discharge at Tete. Immediately before the opening of the conference he arranged for the Portuguese delegation to be flown over the Zambezi, and some if its tributaries, in Angola and from its mouth to the Victoria Falls landing at various places along the river in Mozambique[87]. Nevertheless, valuable though such reconnaissance was, it provided a poor substitute for the detailed first-hand experience of the British delegation.

The agenda for the conference and a transcript of the agreed conclusions are given in Appendix 2.

The two delegations appear to have left the conference well satisfied with the conclusions, although almost certainly with different conceptions of the purpose and outcome of their deliberations, conceptions which probably also differed from those of their own politicians. Cabrita had already formed a clear opinion of the benefits which could be achieved through multiple purpose development of the basin (hydroelectricity, navigation, irrigation and flood control), especially in Mozambique, and of the need for international co-operation (see Appendix 2, conclusions 1 and 5 proposed by him). Portuguese politicians were, however, suspicious of the idea of a Zambezi River Authority. By contrast the British politicians, who originally proposed the idea of a Zambezi Conference, presumably supported the establishment of such a body. However, nothing has been published by any member of the British technical delegation which suggests that they were interested in anything more than a piece-meal development of the basin's resources which, for the most part could

* Given as his inaurgural speech to a chair in hydraulics at the Instituto Superior Technico in Lisbon.

be achieved through co-operation simply between Northern and Southern Rhodesia.

Had Cabrita realised this difference of approach he might have sought stricter guarantees, over the downstream effects of the Kariba Project, other than those contained in Item 2 of the Conclusions. The wording he proposed for this item indicates a lack of understanding both of the short-term effects of the dam's construction and of the long-term effects of its operation. In the short-term, the British committed themselves only to maintain a mean annual discharge in excess of 283 m^3/s. This would have permitted them to reduce the discharge to zero for part of the year if they had so wished. The provision would not, therefore, have guaranteed the flows necessary for downstream irrigation. Furthermore, zero discharge from Kariba would have caused dramatic downstream environmental effects including salt intrusion at the delta; such effects were not, apparently, considered by Cabrita. The clause guaranteeing minimum flows for navigation through the dry season might have prevented such consequences, but it is so imprecise that any dispute which might have arisen over its application would have been virtually impossible to resolve. It appears that, for the long-term, Cabrita did not anticipate unseasonal discharges from the dam. The rather puzzling clause specifying that at no time should outflow exceed inflow applied, in any case, only to the construction period. The procedure for the dam's operation after its completion does not appear to have been discussed in detail, probably because the Portuguese believed that the dam would provide complete regulation of the river resulting in constant discharges throughout the year. This belief persisted through many of their early hydrological investigations of the river.

Cabrita appears to have been happy to accept the allocation for consumptive water use in Angola. The amount allocated, 1.5 x 10^9 m^3/yr or a mean consumption of about 50 m^3/s, was very large compared with Angola's current consumption and would have been sufficient to irrigate up to half-a-million hectares. On the other hand it represented only about 3% of Kariba's mean annual inflow whereas the total runoff from Angola probably provides 20% or more. The conference delegates had few precedents on which to base their recommendations and wisely made provision for a review of the allocation at a later date.

The British delegates appear to have been equally satisfied with the conference's conclusions. They had obtained a commitment to install river gauges in Angola and Mozambique, and an agreement that the Central African Council should act as collator of climatic and hydrological data and other relevant information until such time as an international river authority would be established. Furthermore, they had ensured, as far as possible, that there would be no Portuguese objections raised to the building of the Kariba Dam, that Angola would not undertake works that would prejudice its operation and that no onerous restrictions would be demanded in respect of maximum or minimum downstream discharges.

Following this technical conference the conclusions were referred to the respective governments but no further action appears to have been taken. Portugal remained suspicious of the idea of a river authority, despite the fact that Mozambique might have stood to gain most from its creation. Meanwhile, British interests were adequately safeguarded through the Portuguese agreement to co-operate with the Central African Council. Nevertheless, the idea was kept alive for a time as further documents were appended to those of the *Conferência do Zambeze*, which indicated that the spirit of co-operation was continuing between the British and Portuguese authorities. In May, 1951, the report published by the Inter-Territorial Hydro-Electric Commission, entitled *Kariba Gorge and Kafue River Hydro-Electric Projects*, repeated the initial call for the establishment of a Zambezi River Authority. The arguments were further rehearsed by Debenham, the Professor of Geography at Cambridge, in August 1952[88], but, thereafter, the idea was largely forgotten. Kariba was placed under the control of a body which is international in nature but concerned only with power generation and distribution. Mozambique created a river authority with much broader powers which appears to have enjoyed good relations with the operators of the Kariba Project. Nevertheless, the activities of the two were never integrated into an international river basin authority. The most recent initiative in that respect appears to have been a reference made by Prime Minister Barrow of the Central African Federation, following the devastating floods of 1957 and 1958, to the possible benefits that such a body might have provided in gathering and disseminating information[89].

The Missão de Fomento e Povoamento do Zambeze* (MFPZ)

Rather surprisingly Cabrita's name does not appear to have been linked directly with subsequent Portuguese initiatives in the Zambezi basin. For a time, the name of Professor A Abecasis Manzanares became prominent and, in March, 1956, he became involved in discussions with the Minister of Overseas Territories on the possible development of the Zambezi Valley. They had before them the report from an exploratory survey made by members of the team which had recently completed a detailed hydrological study of the Revué basin. The text of the dispatch issued after this meeting appears in Appendix 3. This initiative reveals a new priority in Portuguese plans for the river - the generation of hydroelectric power. This may, to some extent, have been a reflection of the interests of the survey team whose previous work, in the Revué basin, was primarily concerned with hydroelectric potential. On the other hand, the dispatch issued in March, 1956, emphasized one project, the proposal to dam Cabora Bassa Gorge, which was equated with the Kariba Project. It would not be unrealistic, therefore, to suggest that the rapid progress which was, at that time, being made in the construction of the Kariba Dam was a major factor in the awakening of Portuguese interest in the hydroelectric potential of the lower Zambezi. A further point of interest in the dispatch of March, 1956, is that it indicates that the authors had a keener awareness of the possible downstream effects of the Kariba Dam than was shown in the published conclusions of the 1950 conference. The dispatch notes, in particular, the need for 'constant and complete knowledge of the development of the Kariba project'.

In May and June, 1956, Manzanares undertook a visit to the Zambezi and published his own report on its potential for development (see Appendix 4 for an abridged version of his report). This report had considerable influence over the investigations and planning undertaken in the lower Zambezi Valley for the following ten years or more. Its importance is acknowledged in the introduction to the *Plano Geral* where it is extensively quoted. A number of features in Manzanares' report are of particular interest:

a) he continued to give priority to the Cabora Bassa Project but sought

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* The Zambezi Development and Settlement (Colonization) Authority.

to demonstrate that if it were developed as a multiple purpose project, in association with European settlement and the exploitation of the valley's mineral resources, it would bring far greater benefits than simply as a single purpose project;

b) he suggested that the British Central African territories would provide markets for the hydroelectric energy and would make considerable use of a navigation channel along the river;

c) he emphasized the similarity between the Kariba and Cabora Bassa projects but failed to recognize important differences between the hydrological operation of the two reservoirs.

d) his failure to recognize these differences led to an over-optimism in the capabilities of the proposed project which persisted throughout much of the subsequent period of investigation and planning (for example, Manzanares believed that the discharge would be 'totally controlled inter-annually' and that floods would be 'readily controllable');

e) he recognized that the hydroelectric potential at Cabora Bassa Gorge was many times greater than the current level of consumption in Mozambique and consequently suggested that a programme of phased construction for the power stations should be adopted; and

f) he recognized that Lake Cabora Bassa would trap virtually all incoming sediments, but he considered the implications of this only in terms of the increased power of erosion of the discharges downstream.

The report by Manzanares, in emphasizing the potential for multiple purpose development of the Zambezi, was repeating the earlier ideas of Cabrita and also reflecting the world-wide interest in multiple purpose river basin development which had been awakened by the success of the TVA. The TVA was also recognized, at the time, by the Portuguese authorities as providing a possible administrative model for the development of the lower Zambezi[90]. On 16 March, 1957, they established a form of river basin authority for the Zambezi entitled the Missão de Fomento e Povoamento do Zambeze (MFPZ). Like the TVA, the MFPZ cut across existing forms of administration being established by ministerial decree within the Ministry of Overseas Territories and, therefore, directly responsible to, and financed by, Lisbon rather than the provincial administration in Mozambique. Its terms of reference, set out below, were, however, narrower than those of the TVA being restricted to investigation and planning:

to undertake systematic investigation of the resources of the hydrographic basin of the Zambezi River in the territory of Mozambique, to organize plans for their exploitation and development and to prepare designs for the projects which would be selected[91].

The MFPZ adopted the procedures which had been developed for studying the resources of other river basins in Mozambique and in other Portuguese territories. In the case of the Zambezi these entailed the production, in three stages, of a large number of reports over a period of eight years. The first three volumes, which appeared within two years of MFPZ's formation, were entitled *Relatório Preliminar* (Preliminary Report). These volumes contained a summary of available information about the resources of the basin, an outline of possible strategies for development, a programme for the final two stages of the MFPZ's investigations and cost estimates for this work.

By 1961 the first of these two stages was ready for publication. Entitled *Vale do Zambeze: Esquema Geral de Fomento e Ocupação* (Zambezi Valley: General Scheme for Development and Colonization - referred to, herein, as *Esquema Geral*), this work appeared in twenty-three separate reports (thirty-one volumes)*. From general surveys of climatic, hydrological, topographical and ecological information the MFPZ investigators identified fifty-seven possible sites for hydroelectric development on the Zambezi's tributaries, four sites for possible dams on the main river and forty zones for potential agricultural development within the valley. The *Esquema Geral* also contained geological information and reports of the region's social and economic characteristics.

The final stage of the MFPZ's investigations was completed in 1965 with the publication of *Vale do Zambeze: Plano Geral de Fomento e Ocupação* (Zambezi Valley: General Plan for Development and Colonization - referred to, herein, as *Plano Geral*). The *Plano Geral* comprised a main text with forty-one appended reports, making up a total of fifty-

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* The details of these reports are given in Bibliography 1 of this thesis. Hereafter, reference will be made using the report numbers which appear in this bibliography; for example, *Esquema Geral, 10*. Multi-volumed reports are referred to in the following way: *Esquema Geral, 7.1* and *Esquema Geral, 7.2*.

two volumes*. The *Plano Geral* appendices summarized and elaborated the information gathered for the *Esquema Geral* and, in addition, contained detailed plans and information for certain selected priority projects. The main text provided a synopsis of the entire study with recommendations for a detailed strategy of development for the basin. The principal elements of the *Plano Geral* are as follows:

(i) the construction of the Cabora Bassa Dam, and other mainstream dams, primarily for generation of hydroelectricity and development of navigation on the river;

(ii) other works necessary for establishing a navigable channel along the river and for trans-shipment to a deepwater port;

(iii) selected agricultural projects of various types, both in tributary basins and in the main alluvial plain; and

(iv) mining and industrial projects, in particular, the establishment of an iron and steel industry based on deposits of coal and iron ore in the basin.

The authors of the *Plano Geral* amplified the view, expressed by Manzanares, that Cabora Bassa should be a multiple purpose project. They believed its construction would fulfil the following objectives:

- to regulate the flows of the Zambezi River in order to guarantee minimum flows sufficient to make the section downstream of Mepanda-Uncua navigable;
- to reduce, very considerably, the intensity and frequency of floods downstream of Cabora-Bassa Dam;
- to provide total or partial control over the eventual irregularities in discharge arising from possible abnormalities or errors in the operation of the Kariba Project;
- to trap sediment discharges associated with a hydrographic basin which, including that regulated by Kariba, is of the order of 900 000 km²;
- to produce large quantities of electrical energy at exceptionally low cost;
- to establish navigation over a distance of 300 km between Zumbo and Cabora-Bassa, using the reservoir itself, and thus to improve the flow of products from the 'hinterland', in particular of coal and iron bearing minerals; and

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* Details of the appendices are given in Bibliography 1. References to individual volumes are made in a similar format to that adopted for the *Esquema Geral* (see above). The main text is referred to as: *Plano Geral, Texto*.

to lead to the establishment of fishing and tourist industries[92].

Nevertheless, in the succeeding paragraphs of the *Plano Geral Texto* it becomes apparent that in the practical application of these objectives, at least in the short-term, the authors were proposing the development of Cabora Bassa rather more as a single purpose than as a multiple purpose project:

> The most important objectives are the regulation of liquid and sediment flows and the production of electrical energy. In fact the most important objective for the Cabora-Bassa Project, in the short-term, could become the ability ... to transform the Zambezi River downstream of Mepanda-Uncua into a very profitable navigation route through its effects on the economic development of the region.

With the publications of the *Plano Geral* the initial work of the MFPZ was complete although it continued working on a number of studies. Without substantial public investment, however, none of the development proposals could proceed. In particular, the plans, as formulated, demanded the construction of the Cabora Bassa Dam as a pre-requisite to further development, because of the importance that had been placed in the *Plano Geral* on the establishment of a navigation system to provide the necessary transport and communications and, to a lesser extent, cheap electrical energy.

On 15 January, 1966, the Ministry of Overseas Territories, in Lisbon, created a new body, Grupo de Trabalho para o Zambeze (Working Party for the Zambezi). Its terms of reference were to complete the technical and financial studies which would be necessary before international tenders could be sought for the construction of the Cabora Bassa Dam and, also, to direct the continuing work of the MFPZ. Apart from commissioning various detailed theoretical model studies of the dam structure, the power houses and the spillways, the main concern of this new body was to obtain the necessary finance for the dam's construction. It was clearly apparent, by this time, that the sale of modest amounts of energy in Mozambique and the levying of tariffs from navigation would not provide sufficient revenue to attract the necessary captial for such a large project. It was inevitable, therefore, that the possibility of bulk energy exports, in particular to the RSA, would be investigated and that, as a result, the generation of hydroelectric power would become the primary purpose of the project.

The Portuguese Government awarded the contract for construction of the Cabora Bassa Dam to the Paris based consortium ZAMCO (Zambeze Consórcia Hidro-eléctrico), on 4 September, 1969. On 27 February, 1970, the MFPZ and the Grupo de Trabalho para o Zambeze were replaced by a single body the Gabinete do Plano do Zambeze (GPZ - Bureau of the Zambezi Plan) whose initial and principal purpose was to supervise the execution of the dam construction work and other associated works such as the resettlement of people displaced by the lake.

In the period from 1966 to 1974 the majority of the reports and investigations on the Zambezi concerned the Cabora Bassa Project. These included, at a very late stage, a number of investigations of the possible environmental effects of the project. In addition to work directly relevant to the dam, a number of studies were also undertaken of mineral and industrial projects, agricultural potential and navigation. Reference is made to these studies in subsequent sections of the thesis.

The construction of Cabora Bassa Dam: political background

> ... it is necessary to ... expand the real guide-lines of the great Portuguese realities in Africa, in this particular case of the construction of the Cabora Bassa Dam ... Portuguese overseas policy ... is, above all, concerned to further the systematic enhancement of the land and its people, without colour bars, guided by the sense of collaboration which has always been offered to neighbouring countries, even those which cause Portugal constant problems on the international scene. The Cabora Bassa project cannot be viewed in isolation as a mere system for the production and distribution of electrical power; it should be seen as the basic infra-structure of a vaster, more ambitious plan, the General Plan for the Development of the Zambezi Valley which, when carried out, will bring the population affected by it extraordinary social and economic benefits, which can hardly be paralleled by any other African country.

Taken from an official Portuguese Publication in English[93].

> The Portuguese are engaged in a colonial war against the people of Mozambique. The establishment of a mass of white settlers

> is part of a strategic plan. The aim is to create a human barrier along the Zambezi to prevent FRELIMO forces from advancing further south. At present the Portuguese colonial government has little more than a superficial economic hold on Mozambique. The realization of the dam would more firmly implant the Portuguese industrial interests in the colony - a situation which will make more difficult the wresting of independence from an otherwise notoriously backward European country.

Taken from an offical statement, in English, by Frelimo[94].

The foregoing statements, each published in about 1970, present the opposing positions adopted in the intense political debate, which took place between 1968 and 1974, over the construction of the Cabora Bassa Dam. In reality, although the conflict between Frelimo and the Portuguese authorities dominated the political debate, there were other important facets to the political issues which surrounded the dam's construction; the power of many political and economic interest groups influenced the eventual course of events. Since the main purpose of the present discussion is to provide background material for the remainder of the thesis it will only be possible to discuss these political complexities in outline. More detailed analyses are available in the literature[95].

In the period from 1930 to 1970, Portugal's policy regarding its African colonies was neither static nor completely uniform. It was noted earlier in this chapter that from the beginning of the *Estado Novo*, in 1930, until the 1950s there were few new Portuguese initiatives in Africa apart from the imposition of direct administration which achieved more effective exploitation of African labour. After 1950, however, Henriksen (1978, p134) suggests that Portugal became increasingly interested in obtaining wealth from Africa, in justifying to other European powers its retention of its colonies and in settling in them Portuguese immigrants. The Portuguese National Development Plans of 1953-58 and 1959-64 made large allocations for expenditure in Mozambique. The money was used, primarily, in infrastructure requirements (transport) or in creating irrigation projects which would support white settlers*. By

* It was during this period that the irrigation schemes for the Limpopo, which had been discussed for twenty years, were finally implemented.

contrast, very little money was allocated to education and social services; nothing in the first period and 14% of total expenditure in the second[96]. Large financial incentives were offered to Portuguese immigrants and, as a result, there was a rapid increase in the white population of Mozambique as the following approximate figures show[97]:

1930	20 000
1940	27 000
1950	48 000
1960	97 000
1970	150 000 (estimated)
1973	200 000 (estimated)

Throughout this period, the Portuguese authorities were divided between those who believed that Portugal's interest would best be served by rapid economic development of the African colonies, involving greater participation by foreign capital, and those who were intensely suspicious of any move towards a more open economy. By the late 1960s the arguments of the former group were gaining ground as is indictated by the growing foreign involvement in Mozambique, particularly in mineral prospecting and in industrial projects[98]. The political climate was, therefore, favourable to the implementation of the schemes proposed in the *Plano Geral* which could not have been considered without large amounts of foreign investment.

One can only speculate on the principal motive, whether political or economic, of the Portuguese authorities when they established the MFPZ in 1957. Within a decade, however, a new factor had arisen which was to have a considerable influence on their policies in Mozambique during the late 1960s and early 1970s - security.

Early in 1961 the first Angolan uprising had taken place. Its ruthless suppression marked the beginning of a period of increasing military involvement in Africa which, with its increasing cost in both human and financial terms, was a key factor in bringing about the overthrow of the government of President Caetano on 25 April, 1974. Furthermore, Portugal's African wars were not only a drain on the country's manpower and economy but also provoked strong international condemnation, particularly from the Organisation of African Unity and the United Nations. When, in 1965, the Cabora Bassa Project was first debated by the Portuguese Government the extent of their future military involvement in Mozambique was not foreseen, although the Frelimo uprising in northern Mozambique in 1964 had already imposed uncomfortably high costs.

For the Portuguese authorities the implications, as regards the Cabora Bassa Project, of the African wars were felt in various ways. With the rapidly escalating cost of the wars neither public opinion in Portugal nor the government exchequer would have supported heavy public investment in such a project. Furthermore, international opinion and the worsening security situation would have prevented Portugal from obtaining international loans (for example, from the World Bank) and made many governments and financial institutions cautious about investing in Mozambique. On the other hand, Portugal hoped to persuade western governments, and the governments of Rhodesia and the RSA, that it was in their own interests to support the Portuguese wars against 'communist insurgents'. The Cabora Bassa Project would help to consolidate their position by creating a physical barrier against further nationalist advances, a means of strengthening the European presence in the region and a symbol of Portuguese determination to retain control of Mozambique, which would inspire increasing western investment. As the information pamphlet from the GPZ (1971 a) candidly proclaims:

> ... the Cabora Bassa project will establish, in the Province of Mozambique, an important monument to consolidate Portuguese policy in the provinces of Africa.

In the event, it was the support of the RSA which proved crucial for the implementation of the project; that support is discussed below.

The decision to proceed with the construction of the Cabora Bassa Dam provoked sharp international reaction and provided a focus for increased nationlist resistance. Jundanian (1974) reports that:

> many high ranking military officials [have remarked] that strictly from the point of view of <u>military containment</u> of the liberation groups, Cabora Bassa is a tactical error. The dam ... created a tangible symbol that bolstered nationalist morale at a time of sagging fortunes in Niassa and Cabo Delgado and rallied international support against what is preceived as a plot to ensure white domination in southern Africa. (p252, emphasis in original)

The activities of the guerrillas in Tete obliged the Portuguese authorities to provide heavy military protection for the dam builders and their supply routes. At the same time strong international condemnation obliged them to undertake a strenuous public relations campaign. The protracted discussions over the financing of the dam had caused it to be detached from other *Plano Geral* proposals and to be regarded as a single project, solely for power supply to the RSA. The principal argument used in Portugal's campaign, therefore, was that the dam was an integral part of the development of the Zambezi valley, as set out in the *Plano Geral*, and that such an ambitious development scheme could not fail to bring prosperity and vastly improved conditions to the African population of the region[99]. It was also argued that, in the short-term, the dam would bring local benefits through the villagization programme (which was being carried out both to resettle those displaced by the reservoir and as a counter-insurgency measure), through the wages of labourers on the construction project and through the stimulus provided to the local economy*. Henderson (1972) questioned the reality of these benefits even from a Portuguese perspective and suggested that a number of smaller projects would have brought greater benefits for a smaller total investment. The Portuguese answered such criticisms by pointing out that the capital which had been made available for Cabora Bassa would not have been available for alternative projects[100].

Undoubtedly the involvement of the RSA in the implementation of the Cabora Bassa project was of great economic and political significance. Davidson (1972) has suggested that 'The Cabora Bassa project has become ... a predominantly South African one'(p41). He interpreted this involvement as part of white south Africa's plan to extend its economic and political hegemony over the territories of southern Africa in order to strengthen the apartheid system. As with Portugal, however, the attitudes of those within the RSA to the project were many-sided. According to a number of accounts[101], there was initially considerable opposition within the RSA to its becoming directly involved in such

* The construction contract stated that certain products, such as cement, had to be bought locally and that, in addition, 28% of the initial contract price had to be spent on Portuguese or Mozambican goods or services. Vidigal (1970, p19) estimated that this would total about 3 million contos (US $ 100 million).

a project. The principal debate centred around whether or not the RSA should commit itself to buying large quantities of energy from Mozambique. Without such a commitment the Cabora Bassa Dam would not have been built since there were no alternative markets in the region for large quantities of electrical energy. On the other hand, white nationalists in the RSA feared long-term dependence on an energy source beyond the country's borders, especially in view of the growing instability in Mozambique.

The supply of cheap electrical energy is crucial to the economy of the RSA, where the rate of growth of consumption has been sustained at a higher level, and for a longer period, than in almost any other country in the world (see Chapter 4). Renfrew Christie* has developed the argument that abundant, reliable and, above all, cheap supplies of electrical power have been essential for the establishment and growth of the present system of mining and manufacturing industries in the RSA and, thus, for the creation of the apartheid system. White industrialists, Christie maintains, were able to increase the level of mechanization and displace labour, at times when labour organization amongst the black workforce had threatened industrial output, by making use of the country's highly developed electricity supply network. They were, therefore, very reluctant to allow the network to become dependent on imported supplies. Since 1948, when the large private utility, the Victoria and Transvaal Power Company, was taken over, the bulk of South Africa's electricity supply system had been controlled by a single public corporation. The corporation, Escom, has supplied energy predominantly, from thermal power stations using cheap, locally-mined coal.

The views of Escom's personnel became influential in the debate about the Cabora Bassa Project. At first they were strongly opposed to any agreement to import power from Mozambique. There are a number of factors which may have caused them to reverse this decision. The utility was having difficulty raising the necessary capital for its expansion programme and was moving towards a policy of self-financing; it was having difficulty in providing sufficient numbers of skilled operators

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* Pers. comm. October 1978. It is understood that Christie has developed his ideas in a D Phil thesis prepared for the University of Oxford.

for its generating plant; and, it was moving away from its reliance on coal in order to conserve coal deposits and reduce the demand for cooling water. In addition, at that time, nuclear power was not considered to be a possible alternative.

Undoubtedly, Escom's change of heart was not solely attributed to technical factors such as these but also reflected policy decisions by the Government. It reflected attempts which were being made to expand the markets for South African goods and services, to acquire new sources for raw materials*, to support neighbouring regimes which were not openly hostile to the apartheid system and to create a southern African water and power grid which would increase South African dominance in the region. The idea of a water and power grid in southern Africa, and Olivier's advocacy of such a scheme, have been referred to in the introduction to this thesis.

That the cheapness of the power was a major attraction, was not as convincing a suggestion at the time of the decision as it subsequently became. Vidigal (1970, p10-12), in a study of the characteristics of the Escom system, concluded that with the long transmission distance Cabora Bassa's power was barely competitive with Escom's cheap coal generation. It was only after the publication of a report which concluded that far larger quantities of power could be made available to Escom during the project's first phase, and after the feasibility of using high voltage direct current transmission had been established, that a price advantage could be shown to exist for Cabora Bassa's power. Subsequent price inflation, particularly since the 'oil crises' of the 1970s, has considerably increased that advantage and will continue to do so for as long as the price paid by Escom remains fixed. The advantage would be increased still further if the original agreement to cut the price by over 30% after twenty years were to be implemented. (Further discussion related to the advantages and disadvantages, to the parties involved, of the present arrangements to supply power to Escom is contained in Chapter 4).

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* The Anglo American Corporation was becoming increasingly involved in mineral prospecting in the Zambezi basin at the time.

After protracted discussions an agreement between Portugal and the RSA was reached which was acceptable to both sides. Portugal would get its dam and, moreover, the project would be self-financing. Provision was also made for Escom to help supply the power demand in southern Mozambique. In due course, it was hoped, the revenue earned by Cabora Bassa could be used to finance further projects in the region.

The RSA, for its part, would have been well satisfied with the agreement reached. Escom's initial commitment had been fixed at the minimum required to finance the project. Fears that the agreement would make South Africa's electricity grid vulnerable to outside forces could be rejected because Cabora Bassa would never supply more than 8% of Escom's installed capacity, and any loss of supply could be made good from new installations within six months[102]. In negotiating the agreement the RSA was in a strong position since Escom had been, hitherto, self sufficient in energy and had very low tariffs; it was, therefore, able to insist on an extremely low rate for Cabora Bassa's power and to impose certain other conditions. Amongst these was a stipulation that the power should be supplied through an untapped d.c. line. Furthermore, the threat of withholding agreement over Cabora Bassa was used as a lever to persuade Portugal to agree to the Kunene Project, in Southern Angola, which the RSA hoped would supply water and power to Namibia and thereby strengthen South African control over that territory[103].

From the outset the leaders of Frelimo, together with many people around the world who supported the cause of Mozambican independence, were strongly opposed to the building of the Cabora Bassa Dam. As early as 1968, before its construction had been fully authorized, Frelimo's president, Eduardo Mondlane, had resolved that Frelimo's opposition to the dam would become a test of its strength against the Portuguese regime.

> If we do not destroy the Cabora Bassa scheme, or at least make it twice as costly, we shall have received our greatest setback[104].

So great did Frelimo's leaders consider the strategic significance of the dam project that they went against their stated policy of avoiding the destruction of development schemes which Mozambicans would inherit once independence had been won[105]. Whether, as some have suggested, the complete destruction of the dam project was, in reality, never contemplated thus explaining, perhaps, why no successful attacks on the construction site were made can only be a matter of conjecture. Such a proposal appears unlikely since it was acknowledged that the completion of the project would almost certainly make Frelimo's task of winning independence from Portugal more difficult.

Frelimo began its offensive in Tete in March, 1968, and claimed to have encountered South African troups operating in the region[106]. Attacks on road and rail transport disrupted supplies to the dam site which increased construction costs and forced the Portuguese authorities to strengthen their military presence, including the provision of armed convoys at all times. Frelimo's activities appear to have been responsible for some delays in construction but their effects were minimized by careful contingency planning by the contractors. On the other hand, the work of the GPZ and of the mineral prospecting companies operating in the valley was badly disrupted since field survey teams were no longer able to operate unprotected in remote areas. For example, river gauge records for some of the remote tributaries show periods of interruption which were undoubtedly due to Frelimo's spreading influence.

For supporters of Frelimo in other parts of Africa, in western Europe and the USA opposition to the Cabora Bassa project became an important focus in their campaign to win support for the cause of African liberation in Mozambique. This campaign achieved widespread publicity by bringing to the public attention the effects of Portugal's colonial policies in Mozambique, the extent of the involvement of other Western governments in supporting the project and the advantages which the Cabora Bassa Dam would bring to the apartheid system in the RSA as well as to the illegal regime in Rhodesia[107]. The diplomatic efforts of President Kaunda of Zambia, during 1970, caused the Italian Government to withdraw its pledges of financial support for the project. Furthermore, political pressure groups in Sweden caused their government to intervene to prevent the electrical company, ASEA, from participating in the project. Nevertheless, the overall achievements of the publicity campaign in support of Frelimo were no more effective than the military campaign in halting the dam's construction.

The political aspects of the project to which Middlemas (1975) devotes considerable discussion are those surrounding the formation of the construction consortium and the provision of investment captial*. This discussion is of interest becuase it illustrates the practical effects of political factors during the construction phase. Such factors included the desire by Portugal to have a largely self-financing project and, yet, to retain a significant Portuguese stake in the undertaking; the increasing importance of South African involvement; the reluctance of Portugal to allow British firms to participate following Britain's attempts to strengthen the UN's economic sanctions against Rhodesia, by placing a naval blockade on the port of Beira; and the effects of the diplomatic and political campaign in support of Frelimo. Lists of companies which eventually formed the ZAMCO consortium may be found in the references[108].

The Lisbon coup, of April, 1974, removed the major strategic considerations from the debate and independence for Mozambique suddenly became a real and imminent possibility. The argument that the Cabora Bassa Dam would reinforce Portugal's hold over the colony, particularly if plans to settle a large number of Europeans in the Zambezi valley materialized, could now be discounted. Although Frelimo does not appear to have made any official statements, indicating a change of policy towards the project, a number of its sympathizers began to speculate on the role which the dam might play in an independent Mozambique. Some, such as Radman (1974 b), saw the project as a considerable asset**:

> It is true that under present arguments, South Africa would be the major buyer of electricity generated by the dam as long as the energy requirements in the Zambezi valley are negligible. This need not always remain the case. The future rulers of an independent Mozambique will be in the position to make such decisions. The dam may prove to be a great asset in that surely

* The two are closely related because the Portuguese authorities stipulated that the consortium must supply the bulk of the project's finance.

** The paper from which this quotation is drawn was published in summer 1974, as a re-draft of a seminar paper presented in November 1972. The main substance of the paper was, therefore, written before the Lisbon coup, which indicates that such ideas were being discussed in academic circles even before the project's importance in the liberation war was removed.

> not too distant future. To suggest that the dam should be built then rather than now is unrealistic because experience teaches that opportunities often vanish when ignored. Moreover, there is a certain irony in objecting to the efforts of a colonial administration to improve the permanent infrastructure of the colonial territory when so much criticism is directed at former colonial administrations for having failed to foster development while they were in control. (p90)

It is clear that Radman believed, without question, that the dam would 'improve the permanent infrastructure of Mozambique' and that the government of an independent Mozambique would have considerable freedom in determining how the project would be operated. In this sense he considered the dam to be an apolitical technological artefact. The debate as to whether any piece of technology can be regarded as apolitical is beyond the scope of this thesis, but, as applied to the Cabora Bassa Project, it is of considerable practical relevance. In this thesis a number of important constraints on the freedom of Mozambique's political leaders to determine the way in which the project will be operated are identified. Of these Radman appears to have been unaware. They include technical constraints, such as those arising from the use of an untapped d.c. transmission line to the RSA, economic constraints arising from the lack of alternative markets for the energy produced, and political constraints, imposed by the complex relationship between Mozambique, the RSA and Portugal of which the Cabora Bassa Project is a small element.

<u>The construction of Cabora Bassa Dam: Technical details</u>

Estimates of the energy potential at Cabora Bassa and the capacities of the proposed power station changed considerably between 1956 and 1968. Manzanares (see Appendix 4) estimated the energy potential to be 22 TWh/yr, but gave little indication of how this figure was obtained. Two years later, in the *Relatório Preliminar*, 3, the potential was given as 22.8 TWh/yr; from examination of the details provided it is clear that a considerable overestimation of the project's gross head had been made. Values of installed capacity were not, at that stage, suggested.

In the *Esquema Geral, 22.1*, published in 1961, the guaranteed energy potential was reduced to 13.3 TWh/yr. A suitable value for total installed capacity was considered as 2 300 MW to be achieved in three stages: a 100 MW (4 x 25 MW) surface station on the south bank; a 400 MW (4 x 100 MW) underground station, also on the south bank; and, finally, a 1 800 MW (6 x 300 MW) underground station on the north bank.

Revised calculations for the *Plano Geral*, *55.1*, in 1965, suggested that the guaranteed energy potential might be as high as 16.6 TWh/yr and that the total generating capacity which should be installed was about 2 800 MW. The sequential development of the project envisaged was for a 240 MW (4 x 60 MW) semi-excavated station, a 540 MW (3 x 180 MW) underground station, a 1 000 MW (4 x 250 MW) underground station, all in the south bank, and, finally, a second 1 000 MW station in the north bank. As an alternative, a 51 MW station was proposed should the 240 MW station be too large for the initial demand.

Within two years, the estimated energy potential was once more increased to 18.76 TWh/yr[109]. Few details were published of the basis for this new amendment, but it seems significant that it was made at a time when the Portuguese authorities were courting South African involvement in the project and were anxious to show that very large quantities of energy could be made available within a short period. The ultimate installed capacity envisaged at that time was 3 500 MW made up of five 400 MW sets (one of which would be held in reserve) and three 500 MW sets. It was proposed that either four of five of the 400 MW sets should be installed in a single underground power station as the first phase.

Further details were published later, in 1967, when the tender documents for the project[110] were released following a tentative agreement with the RSA over the purchase of power. The final decision was that three 400 MW sets should be installed in a south bank power station in the first phase, entering production by 31 December, 1973, and that two further 400 MW sets should be installed there, entering production during 1977. The d.c. transmission line would be progressively upgraded enabling the maximum power capacity to be increased from 960 MW in 1973, to 1 440 MW in 1977 and, finally, 1 920 MW in 1980. In the event the line construction and commissioning were completed at least a year ahead of schedule.

Delays in reaching final agreement over power sales to the RSA and in the selection of an acceptable construction consortium led to a two year delay on the construction programme. The result was that in the final contract the first three sets were not due to enter production until 1975, with the fourth in 1977 and the fifth in 1979. In the event, although the dam was completed according to schedule, the first generating set was not ready to begin commissioning trials until August, 1975, and commercial power was not available until March, 1977[111]. Nevertheless, by the end of May, 1979, all five sets were available for commercial power generation. The five sets were, thereafter, operated almost continuously for a period of about three months before the agreed operating pattern was established - four sets in continuous operation with one in reserve or under maintenance.

A summary of the technical details of the Cabora Bassa Project may be found in Appendix 1. Further details of the hydrological aspects are contained in Chapter 3. For fuller accounts of other aspects, including the construction schedule and techniques used, reference should be made to the literature[112]. Caution is necessary, however, in the interpretation of certain published accounts. Many amendments were made to the design of the project, including an important change in the design of the spill gates made after initial tenders had been received, and the technical details in earlier accounts may differ from those of the completed project.

In technical terms, the construction of the Cabora Bassa Dam was far less remarkable than that of the Kariba Dam. By 1969, considerable experience had been gained in the execution of such projects and the dam's design introduced few innovations. Reports, in the technical press of the time, suggest that the site was ideal for a concrete arch dam. In noting the high energy potential, it was remarked that this could readily have been increased, by use of a higher dam, had it not been for the fact that the reservoir which would have been created would have flooded large areas of Zambia and Zimbabwe.

As mentioned above, an important amendment was made to the design of the discharge gates at a relatively late stage following warnings, by one of the consortia which was tendering for the contract, that the original design might lead to excessive scouring downstream of the dam and undermine the stability of the rock walls of the gorge[113]. The *Plano Geral* design had had six gates at an approximate level of 275 m together with a low-level vent at 225 m. The tender documents[114] omitted the vent but, in addition to six gates (8 m x 8 m) at a sill level of 278.5 m, included ten weirs each 14 m wide at a crest level of 327 m. It was this configuration which the consortium questioned. Further hydraulic tests were carried out in Lisbon[115] and, as a result, the present design was proposed with eight gates (7.8 m x 6 m at outlet) at the lower sill level of 231 m, inclined upwards to project the water well clear of the toe of the dam, together with a single weir at a crest level of 321 m.

Although the dam design itself introduced few innovations its construction involved overcoming a number of technical and organizational difficulties. Because of the remote location of the gorge, considerable improvements in the existing transport network had to be made including the construction of new and improved roads, the creation of an airstrip at Songo and the building of a road bridge over the Zambezi, at Tete, to provide access to the railhead at Moatize. At the dam site a new type of rockfill cofferdam, designed to be overtopped by high floods, proved a satisfactory improvement on the temporary works used at Kariba and co-operation from the operators of the Kariba Dam over the timing of discharges also helped to reduce the chance of serious flood damage occuring during construction. Initially the ZAMCO consortium had great difficulty in co-ordinating the activities of the member companies from different countries but the situation improved as work progressed.

On the electrical side, the high voltage d.c. transmission system has drawn considerable attention. The use of d.c. transmission was an important factor in the decision by Escom to buy power from Cabora Bassa since it resulted in lower transmission costs and provided a greater degree of control over the supply. In technical terms, however, the use of d.c. transmission was not innovatory although it was still relatively untried at the voltages and over the distances involved in the Cabora Bassa Project.

Technical journals and news magazines, many of which adopt the position that the discussion of 'political' questions should largely be avoided by the engineering profession, could not avoid comment on the political implications of the Cabora Bassa Project, if only to note the effects of the guerrilla warfare on construction schedules and the costs. The engineering profession was, however, closely associated with the process of political decision making in a number of important ways.

For the Portuguese people their engineering achievements, particularly in the construction of dams during the middle years of the present century, were a source of national pride and a potential source of international prestige. As a result, their more outstanding engineers rose to positions of considerable influence (Trigo de Morais is a notable example). Vidigal (1970) cites the project's prestige value as one of the benefits which would be gained from Cabora Bassa:

> ... the name of the country - and, in particular, the prestige of Portuguese engineering - will gain respect with the completion of such an exceptional undertaking. (p20)

It appears that Portuguese engineers, aware of their country's image in Europe as poor and underdeveloped, wished to prove that they were as competent in the technology of large arch dams as were the French and British engineers who had designed Kariba. It is difficult to assess the influence which engineers ultimately had on the decision to build the Cabora Bassa Dam. Nevertheless, their desire to prove their competence in the design of big dams was reflected in an insistence that the designs for the dam, prepared by the consultants Hidrotécnica Portuguesa should be adhered to closely by the contractors and that all model tests on the structure and spillways should be undertaken by the staff of the Laboratório Nacional de Engenharia Civil in Lisbon. Portuguese engineers regarded themselves as pioneers in the development of techniques for the design of arch dams based on model tests[116], and Cabora Bassa was heralded as a monument to their achievements.

Worldwide, there are relatively few engineers with the expertise and experience necessary to design and build major dams. For this reason a particular consultant or contractor will frequently have been associated with more than one celebrated project. Individual engineers have occasionally played an important role in influencing politicians in decisions regarding proposed projects*, a role which is obviously to their own advantage in so far as it increases the number of projects in which they and their colleagues are able to participate.

One such engineer, Henry Olivier, is closely associated with the Cabora Bassa Dam. As a consultant with Sir Alexander Gibb and Partners, Olivier had been associated with many dam construction projects including the Owen Falls Dam in Uganda, dams in the Indus basin in Pakistan and, most notably, the Kariba Dam. He had hoped to play a major role in the Cabora Bassa Project as part of a consortium to which Gibb and Partners were acting as consulting engineers but, when the contract was awarded to the ZAMCO consortium, Olivier left Gibb and Partners and took an appointment with the South African contractors, LTA**, so that he could continue to participate in the project. With H J van Eck, chairman of the RSA's Industrial Development Corporation and Iron and Steel Corporation, Olivier gave both public[117] and private support to the Cabora Bassa Project. His arguments, based on the belief that there was a need for the RSA to conserve its water and energy resources, were probably influential in ensuring South African's support for the scheme. Subsequently, Olivier's repeated exposition of the international benefits of a southern African power and water network (see introduction) suggests that he is continuing to seek ways of influencing politicians to undertake further dam projects in the region.

Other aspects of the Portuguese plans for the Zambezi valley

The Cabora Bassa Project formed only one element, albeit the most important, in Portuguese plans for the Zambezi valley. The principal feature of other plans may be grouped under the three headings of hydro-electric power, agriculture and navigation. Mineral extraction and industrial development, which also featured in the MFPZ's plans, are discussed in Chapter 4. Much of the following discussion is based on the contents of the *Esquema Geral* and the *Plano Geral* but a number

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* The influence of André Coyne which reinforced the position of those politicians who favoured the Kariba project is a possible example (see discussion earlier in the present chapter).

** LTA, a subsidiary of the Anglo American Corporation, was a major contractor in the ZAMCO consortium.

of other publications have summarized the principal proposals of the several reports. Falcão (1963) gives a detailed summary of the plans contained in the *Esquema Geral*. A number of official and semi-official Portuguese publications[118] describe the contents of the *Plano Geral*. There are also some non-Portuguese sources[119] which provide similar material, but no detailed analytical studies of the plans have been published.

1. <u>Hydroelectric Plans</u>: The *Esquema Geral*, published only four years after the establishment of MFPZ, proposed four further hydroelectric projects on the main Zambezi, downstream of Cabora Bassa, together with fifty-seven possible projects located on the river's tributaries in Mozambique. On the basis of figures adapted from these proposals, and which were subsequently presented in the *Plano Geral*, it is widely believed that the hydroelectric potential of the basin exceeds 50 TWh/yr of which 6.5 TWh/yr could be guaranteed from triburary projects and the remainder provided by projects on the main Zambezi.

The belief that the Zambezi basin in Mozambique is rich in hydroelectric potential is, however, inaccurate and misleading as the following study of the relevant reports shows.

Portuguese engineers have developed techniques for mapping the hydroelectric potential of remote areas for which the available hydrological data are inadequate. Moreno (1964) showed how such techniques could be applied, in Angola and Mozambique, to produce maps of mean annual hydroelectric potential per unit area (kWh/m^2) from maps of topographical relief, mean annual rainfall and mean annual temperature. The work of Moreno is of particular interest for two reasons: the techniques which he used are similar to those employed by the MFPZ in their first studies of the Zambezi basin; and, his map shows the Zambezi basin to be amongst the areas of <u>lowest</u> hydroelectric potential in Mozambique (mostly below 0.1 $kWh/m^2/yr$).

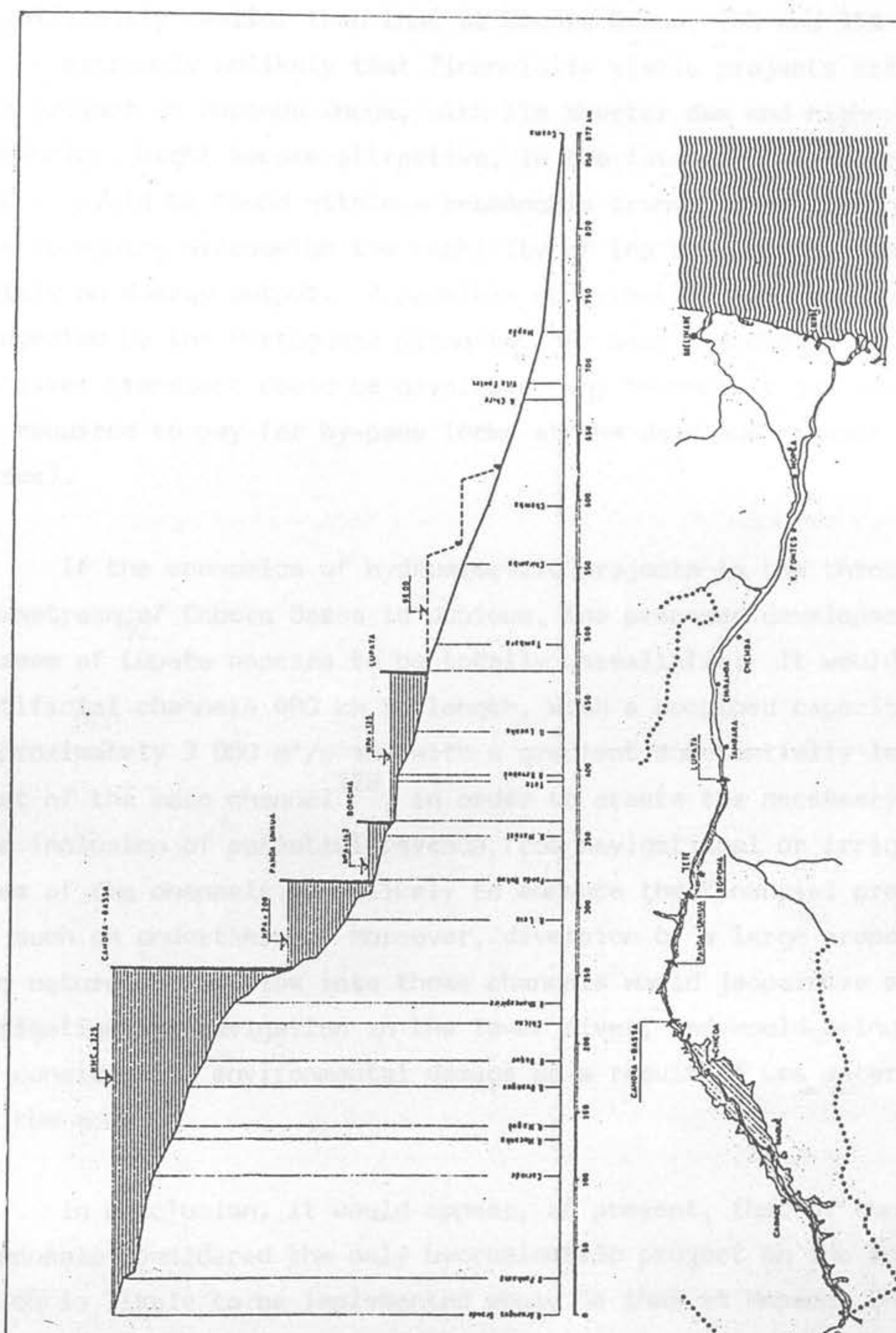
Results obtained by using techniques similar to those of Moreno require careful interpretation. Firstly, the hydroelectric potential thus calculated is confined to the component which derives from rainfall falling only on the catchment under study. Yet, in the case of the Zambezi basin in Mozambique the largest component of the hydroelectric potential derives from river discharges in the Zambezi which enter Mozambique from upstream. Moreno's analysis cannot accommodate such discharges. It is, therefore, important to separate any study of hydroelectric potential into two components; that due to the discharge of the Zambezi and that due to rainfall over the tributary basins. Secondly, Moreno's type of analysis may lead to substantial errors as a result of inaccuracies in the available topographical and climatic maps and because, in regions such as the Zambezi basin, where rainfall is seasonal, the theoretical energy potential could only be translated into firm power output if adequate storage reservoirs could be provided.

a) Projects on the main Zambezi: Reference has been made above to the amendments made to estimates of Cabora Bassa's energy potential over the period 1956 to 1968. Similar amendments were made with regard to other projects, as may be seen from the data presented in Table 3. The *Relatório Preliminar* proposed only two projects downstream of Cabora Bassa - at Boroma and Lupata. The values of energy potential given for these projects were considerably higher than those given in subsequent reports; largely because values of gross head were over-estimated. The *Esquema Geral* introduced two further projects - at Mepanda Uncua and downstream of Lupata; see Figure 7. The proposals contained in the *Plano Geral* are similar to those of the *Esquema Geral* except that use of higher values for guaranteed river flow has resulted in higher estimates of energy potenital. The combined potential is, therefore, close to that estimated in the *Relatório Preliminar*, 46 TWh/yr. Detailed examination reveals, however, that exploitation of the full potential would not, in practice, be possible as the following discussion reveals.

The gorges at Mepanda Uncua, Boroma and Lupata are each wider than that at Cabora Bassa having mean channel widths at their narrowest points of approximately 180 m, 350 m and 250 m respectively. Designs shown in the *Plano Geral* (*Texto*, Fig. 46) indicate that the dam required at Mepandu Uncua would have a crest length of approximately 450 m. The Boroma and Lupato gorges would require dams of considerably greater length. Thus each of the three projects would require structures which would be significantly larger than the dam at Cabora Bassa. In addition, the temporary diversion works, required during the construction period, would have to carry higher flows than those experienced at Cabora Bassa.

Table 3 Details of mainstream hydroelectric projects proposed by the MFPZ for the lower Zambezi.

Location	Relatório Preliminar (1958)	Esquema Geral (1961)	Plano Geral (1965)			
	Guaranteed energy potential (TWh/yr)	Guaranteed energy potential (TWh/yr)	Guaranteed energy potential (TWh/yr)	Firm power (MW)	Head (m)	Guaranteed river flow (m^3/s)
Cabora Bassa	22.8	13.3	16.6	1900	100	2370
Mepando Uncua	--	7.4	10.8	1230	58	2660
Boroma	8.6	2.2	3.2	360	17	2660
Lupata	15.2	3.5	5.5	630	27	2930
downstream of Lupata	--	6.4	10.2	1170	50	2930
TOTAL	46.6	32.8	46.3	5290	--	--
Cabora Bassa as percentage of total	(49%)	(41%)	(36%)	(36%)	--	--



Source: Falcão (1963)

Figure 7: Proposed hydroelectric developments downstream of Cabora Bassa

As a result, the construction of dams at any of the three downstream gorges would, almost certainly, cost more than the Cabora Bassa Dam. Since the values of energy potential at Boroma and Lupata gorges are significantly smaller than that at Cabora Bassa, 20% and 35% respectively, it is extremely unlikely that financially viable projects are possible. The project at Mapanda Uncua, with its shorter dam and higher energy potential, might become attractive, in the future, if a market for its output could be found within a reasonable transmission distance. (In the foregoing discussion the viability of the projects has been assessed solely on energy output. A possible contribution from navigation, suggested by the Portuguese planners, has been discounted because, even if river transport could be developed, any revenue it generated would be required to pay for by-pass locks at the dams and channel stabilization works).

If the economics of hydroelectric projects in the three gorges downstream of Cabora Bassa is dubious, the proposed development downstream of Lupata appears to be totally unrealistic. It would require artificial channels 400 km in length, with a combined capacity of approximately 3 000 m^3/s and with a gradient substantially less than that of the main channel[120], in order to create the necessary head. The inclusion of potential revenue from navigational or irrigational uses of the channels is unlikely to enhance the financial prospects of such an undertaking. Moreover, diversion of a large proportion of the natural river flow into these channels would jeopardize existing irrigation and navigation in the lower river, and would bring the threat of considerable environmental damage as a result of sea water intrusion at the mouth.

In conclusion, it would appear, at present, that of the four proposals considered the only hydroelectric project on the lower Zambezi which is likely to be implemented would be that at Mepanda Uncua. Together with Cabora Bassa, this project would provide a total energy potential for the river, in Mozambique, of approximately 27 TWh/yr (considerably less than the 46 TWh/yr previously suggested). More than half of this amount can already be generated in the south bank station at Cabora Bassa.

b) Projects on the tributaries in Mozambique: Published accounts of the hydroelectric potential on the Zambezi's tributaries show considerable discrepancies. Initially, the MFPZ engineers, using techniques similar to those of Moreno (1964), obtained the surprisingly high total of over 20 TWh/yr for the theoretical energy potential of these tributaries (published in the *Relatório Preliminar*). Of this, they believed that approximately 70% could be exploited by means of over fifty projects, the details of which are summarized in Table 4. In these projects hydroelectricity was regarded as a secondary output; in their proposals the planning engineers were concerned, primarily, with identifying suitable locations for irrigation schemes. Any energy output was seen as being mainly to meet local needs including that required for pumped irrigation.

For the *Esquema Geral* the topographical information, which had previously been obtained from 1:500 000 scale maps, was improved and aerial photographs of some of the project locations were studied. Some refinements in the hydrological analysis, including an allowance for reservoir evaporation, were also made. But the primary data, derived from a limited network of rainfall gauges, remained the same. As a result of these changes the total estimate of exploitable energy was reduced to 7 TWh/yr.

The results published in the *Plano Geral* are self contradictory. In one place[121], the total potential is given as 6.5 TWh/yr* (firm power output, 800 MW). Elsewhere[122], however, the value given is only 0.8 TWh/yr (firm power output, 195 MW). The lower value derives from an analysis of the minimum river flows which might occur one year in twenty. Such an analysis is necessary because the tributaries do not have suitable sites for reservoirs which could provide inter-annual storage. In a development of this analysis, the fifteen projects with the largest energy potentials (firm power greater than 4 MW) were studied in greater detail. When allowance was made for reservoir siltation, reservoir evaporation and loss of hydraulic head due to drawdown, only five projects remained viable. Their combined energy potential was calculated as 0.24 TWh/yr and their total firm power output (on the MFPZ's assumption of 4 000

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* This value, which appears to have been directly derived from the *Esquema Geral* calculations, is widely quoted in subsequent publications.

Table 4 Details of tributary hydroelectric projects proposed by the MFPZ.

	Relatório Preliminar, 3, (1958)		*Esquema Geral, 23* and *24,* (1961)			*Plano Geral, 54* (1965) Tables 22 and 23					
						Theoretical study, 95% guaranteed flow			Detailed study of hydrology of individual projects larger than 4 MW		
	Exploitable energy (TWh/yr)	Number of projects	Mean exploitable energy (TWh/yr)	Installed capacity (MW)	Number of projects	Guaranteed energy (TWh/yr)	Firm power† (MW)	Number of projects	Guaranteed energy (TWh/yr)	Firm power† (MW)	Number of projects
Luia basin	3.83	14	3.2	1400	15	0.17	41.8	15	0.10	24.9	2
Revúboè basin	2.55	14	2.3	1010	12	0.24	60.7	12	0.03	6.7	1
Luenha basin	5.78	16	0.5	180	11	0.19	46.6	12	0.08	19.4	1
Other small tributaries	1.12	8	0.8	200	11	0.05	12.9	14	0.03	7.1	1
Ruo basin (International river, tributary of Shire)	3.28	2*	0.3	85	4	0.13	33.3	4	--	--	0
TOTAL	16.56	54	7.1	2875	53	0.78	195.3	57	0.24	57.1	5

* includes one project on the Luangwa.

† 4 000 hours per year.

hours operation per year) as 57 MW. The MFPZ engineers concluded that:

> Working, therefore, with a broad safety margin, it is evident that of the projects chosen many would be rejected on second analysis either because they would not have reservoirs big enough to regulate totally the inflows of the critical [dry] year or, primarily, in the schemes with power stations at the foot of the dam, because of the substantial loss of head [resulting from the drawdown necessary to regulate the critical inflows][123].

In fact only two schemes of the fifteen examined were considered to be worthy of further examination, at the time, by the writers of the *Plano Geral*. The schemes selected were Luia 6 (16.5 MW installed) and Luenha 7 (13.2 MW installed)*.

Thus, estimates of the energy potential of the tirbutaries in Mozambique vary by more than a factor of ten within the *Plano Geral* although part of this discrepancy may have arisen because the calculations on which the lowest estimates were based were taken from studies of isolated projects. Should more than one project be built on a single tributary the storage capacity of upstream reservoirs would bring additional benefits to downstream projects. On the other hand, because of inadequate data, there remains the real possibility of error even in the most conservative estimates of energy potential. The hydrological calculations were based on general formulae for runoff, which had been developed from studies of other river basins, calibrated by use of the limited river discharge records available. Of the tributaries under consideration the longest data record used was for eight consecutive years whilst some were as short as two years. Within the majority of records the hydrological year 1962/3 was included in the *Plano Geral* studies but, since this was one of the wettest of the last fifty years in the Zambezi basin, its inclusion in such short data records would introduce considerable bias into the results. Calculation of reservoir siltation rates were even more uncertain since no detailed sediment transport data were available. However, the assumed silt deposition rate of 200 $m^3/km^2/yr$ over 75 years does not, at first sight,

* In the section of the *Plano Geral* (*Texto*, p101) referred to earlier, the installed capacity of Luia 6 is given as 477 MW. The Luenha 7 scheme is not even listed.

appear to be unreasonable. Nevertheless, the *Plano Geral* studies for these tributary projects do not, as they stand, merit active consideration without further investigation of the hydrology and sediment characteristics of the rivers at each site proposed. In addition, careful assessment is necessary to determine if adequate storage could be provided to ensure that the required level of power output could be maintained.

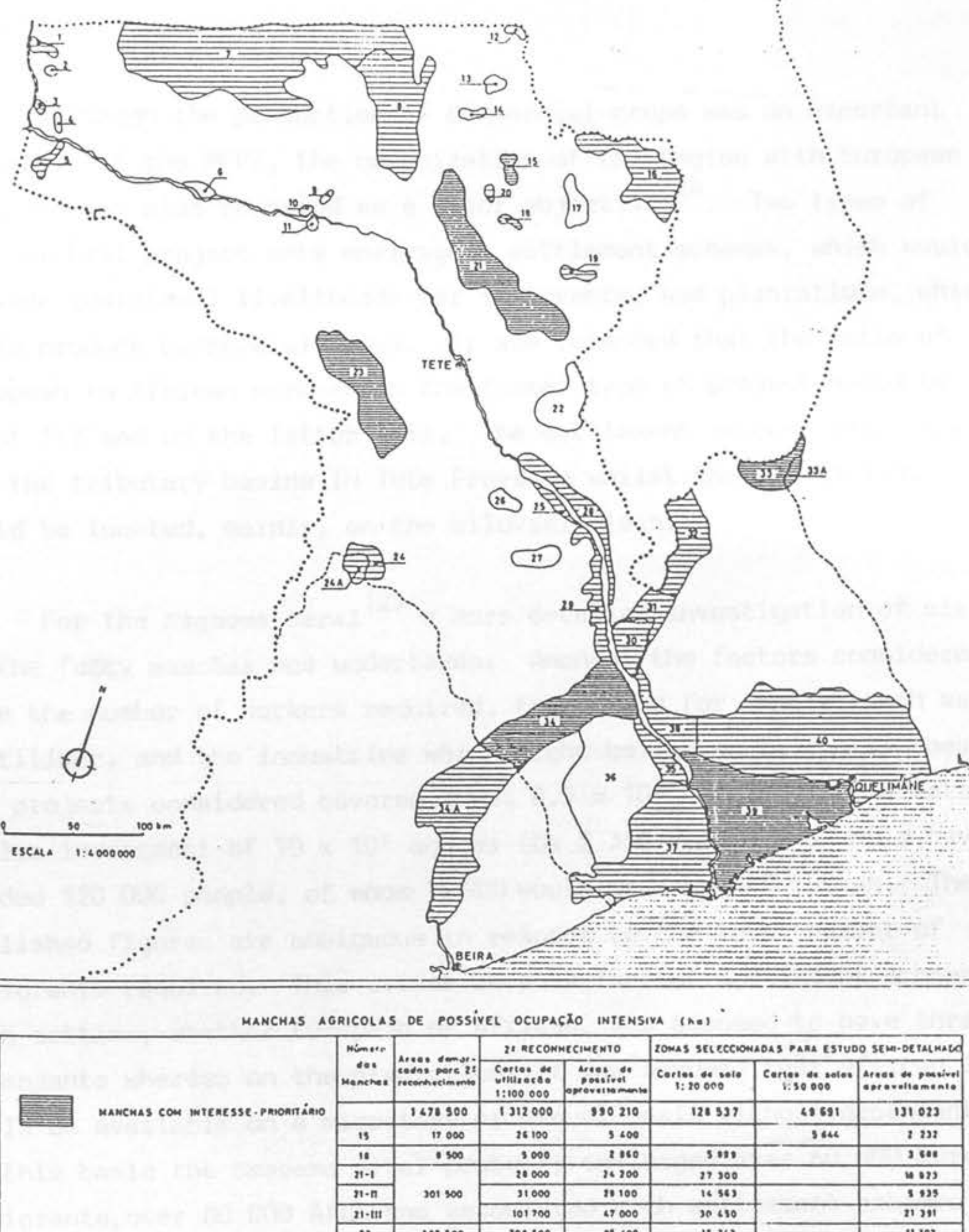
2. Agricultural Plans: The MFPZ planners considered the Zambezi valley as an area of virgin land on which vast agricultural schemes could be established with little difficulty. The basis on which the schemes were to be developed was set out in the *Relatório Preliminar* barely a year after the Agriculture and Forestry Brigade had been established within the MFPZ. Forty areas of high potential, called *manchas**, were identified ranging in size from a thousand to half a million hectares, see Figure 8. In total, these *manchas* covered 5.5×10^6 ha (40% of the basin in Mozambique). The areas of greatest interest were the tributary basins north of the Zambezi in Tete Province and the alluvial plain downstream of Mutarara.

The proposals were given in remarkable detail considering the difficulty of access to much of the region and the poor information which would have been available. The *Relatório Preliminar*, *3*, included descriptions of suitable crop types, annual demand for irrigation water, possible locations for dams and their reservoir storage capacities and, even, estimates of the energy requirements for irrigation pumps. Clearly much of this work was based on a study of the general characteristics of the region rather than on specific field investigations. Nevertheless, the conclusions which were published had a strong influence over subsequent agricultural planning in the region.

A remarkable feature of this early work, as of much of what followed, was the almost total disregard for the indigenous population and their established patterns of cultivation. No attempt was made to estimate the number of people who would be displaced by a given project. Only in the areas of marginal interest, from the point of view of European commercialized agriculture, was any attempt made to study the existing distribution of population and their means of production. A number of

* Literally 'fields'.

Figure 8



MANCHAS AGRICOLAS DE POSSÍVEL OCUPAÇÃO INTENSIVA (ha)

	Número das Manchas	Areas demarcadas para 2º reconhecimento	2º RECONHECIMENTO: Cartas de utilização 1:100 000	2º RECONHECIMENTO: Areas de possível aproveitamento	ZONAS SELECCIONADAS PARA ESTUDO SEMI-DETALHADO: Cartas de solo 1:20 000	ZONAS SELECCIONADAS PARA ESTUDO SEMI-DETALHADO: Cartas de solos 1:50 000	ZONAS SELECCIONADAS PARA ESTUDO SEMI-DETALHADO: Areas de possível aproveitamento
MANCHAS COM INTERESSE-PRIORITÁRIO		1 478 500	1 312 000	990 210	128 537	49 691	131 023
	15	17 000	26 100	5 400		5 644	2 232
	18	8 500	5 000	2 860	5 889		3 688
	21-I		28 000	24 200	27 300		18 823
	21-II	301 500	31 000	28 100	14 563		5 935
	21-III		101 700	47 000	30 650		21 391
	23	187 500	208 500	95 400	15 743		11 103
	33-33A	85 000	59 600	54 250		18 596	13 908
	34	309 000	307 900	226 400	34 582		28 595
	38	570 000	544 200	475 500		25 453	25 358
OUTRAS MANCHAS COM INTERESSE		3 551 200	3 598 400	1 589 610			
MANCHAS COM POUCO INTERESSE		437 500	513 700				
AREAS GLOBAIS		5 467 200	5 424 100	2 579 200	128 537	49 691	131 023

Proposed areas of agricultural development in the Zambezi valley

(Source: *Plano Geral, Texto*, Fig. 26)

such areas were later designated as areas of 'community development' in which attempts were to be made to induce the population to adopt more modern methods of cultivation and to offer their surplus produce for sale*.

Although the production of commercial crops was an important objective of the MFPZ, the colonization of the region with European settlers was also regarded as a major objective[124]. Two types of agricultural project were envisaged; settlement schemes, which would provide individual livelihoods for immigrants, and plantations, which would produce commercial crops. It was intended that the ratio of European to African workers on the former type of project would be about 1:2 and on the latter 1:15. The settlement schemes were intended for the tributary basins in Tete Province whilst the plantations would be located, mainly, on the alluvial plain.

For the *Esquema Geral*[125] a more detailed investigation of sixteen of the forty *manchas* was undertaken. Amongst the factors considered were the number of workers required, the demand for inputs, such as fertilizer, and the industries which might be linked to the schemes. The projects considered covered about 0.5 x 10^6 ha, required a total public investment of 10 x 10^6 *contos* (Us \$ 350 x 10^6) and would have needed 120 000 people, of whom 16 000 would have been European. The published figures are ambiguous in respect to the total number of immigrants required. This arises because for the settlement schemes each settler, whether European or African, was assumed to have three dependants whereas on the plantations it was assumed that African labour would be available on a migratory or casual basis without dependants. On this basis the *Esquema Geral* probably envisaged over 60 000 European immigrants,over 80 000 Africans associated with settlement schemes and approximately 90 000 African migrant labourers on the plantations.

Financial restrictions alone would have made it impossible to proceed with the parallel development of all sixteen *manchas* and, therefore, six priority projects were selected[126]. The public investment needed for these was still formidable: 4.7 x 10^6 *contos*** (US \$ 160 x 10^6)

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* For further details of the effect of Portuguese projects on the indigenous population see Chapter 6.

** At that time the total cost of the Cabora Bassa Project was estimated at 3.8 x 10^6 *contos* (*Esquema Geral*, *22*, Table 8).

over the five-year period 1965-70. From the detail with which the projects were presented in the *Esquema Geral*[127] it appears that proposals for settlement projects were, at that time, receiving greater attention than those for plantation projects. If so, the bias may have resulted from a number of considerations: the difficulty that established plantations, such as Sena Sugar, were experiencing in obtaining adequate labour; the greater adaptability of settlement schemes to incremental and independent development*; and the larger number of Europeans who could be supported for a given public expenditure on settlement schemes.

For the *Plano Geral*, 'semi-detailed' investigation, including soil surveys, of 2.6×10^6 ha revealed a total area of only 130×10^3 ha as being suitable for priority development, half of which would require irrigation, see Figure 8. The details of the agricultural schemes proposed fill fourteen volumes[128] and include detailed consideration of plantation projects in the alluvial plain, and around Milange, as well as settlement projects in Tete Province.

Forestry potential is also discussed both in the *Esquema Geral* and the *Plano Geral* although proposals were largely based on broad classifications of ecological regions. An area totalling 2.2×10^6 ha was identified as suitable for forestry development either through the planting of exotics (as in the northern parts of Tete Province) or through management of existing species. The cost of development and the number of people required were discussed[129] but few other details were given.

After 1965, the agriculture and forestry plans of the MFPZ were largely neglected. The efforts of the MFPZ/GPZ staff were concentrated almost exclusively on work associated with the Cabora Bassa Project. For the agriculturalists, this entailed the establishment, in 1968, of a research station in a resettlement region at Estima and other work associated with resettlement of those displaced by the new reservoir and of the many more gathered into new villages for security reasons

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* Although settlement schemes were largely designed to be independent, for example, in hydroelectric energy, they required cheap transportation to make them economically viable. Their development was, therefore, linked to the navigation proposals.

(see Chapter 6).

The activities of Frelimo guerrillas made it impossible to implement agricultural settlement projects in the more remote regions previously considered and new zones of priority development were sought. The first three regions lay along the Zambezi downstream of Lupata Gorge and around the Shire, see Figure 9, blocks 4, 5 and 6. Outside contractors were invited to submit tenders for undertaking a comprehensive mapping of the land use potential of these regions to include 1:100 000 scale maps (1:50 000 in certain areas) of topography, ecology soils, arable potential, livestock potential, surface and ground water resources and recommended systems of land use[130]. The work was to be based on aerial surveys and to take place between September, 1971, and May, 1974.

The group which won the contract for this work, and subsequently for blocks 9, 10 and 11 (also shown in Figure 9), was R F Loxton, Hunting and Associates (Johannesburg) in association with Empressa Técnica de Levantamentos Aeros (Lourenço Marques) and AOC Technical Services (Johannesburg)*. Hidrotécnica Portuguesa also collaborated in the interpretation of hydrological data.

The results of the Loxton Hunting surveys are the most detailed available for any part of the lower Zambezi valley but, like many of the studies of the MFPZ, they have their limitations as regards their use in the planning of specific agricultural projects. The limitations, some of which Loxton Hunting acknowledged, are considered below:
a) The surveys were based, almost exclusively, on physical and environmental reconnaissance on the apparent assumption, originating from the GPZ, that land use recommendations could be made without reference to social political or economic factors:

> We have not carried out economic feasibility studies; we have little factual information on the particular motivating factors and aspirations of the local people; we have not conducted export market research; we are not informed in detail of Government policy for the Zambezi Valley[131].

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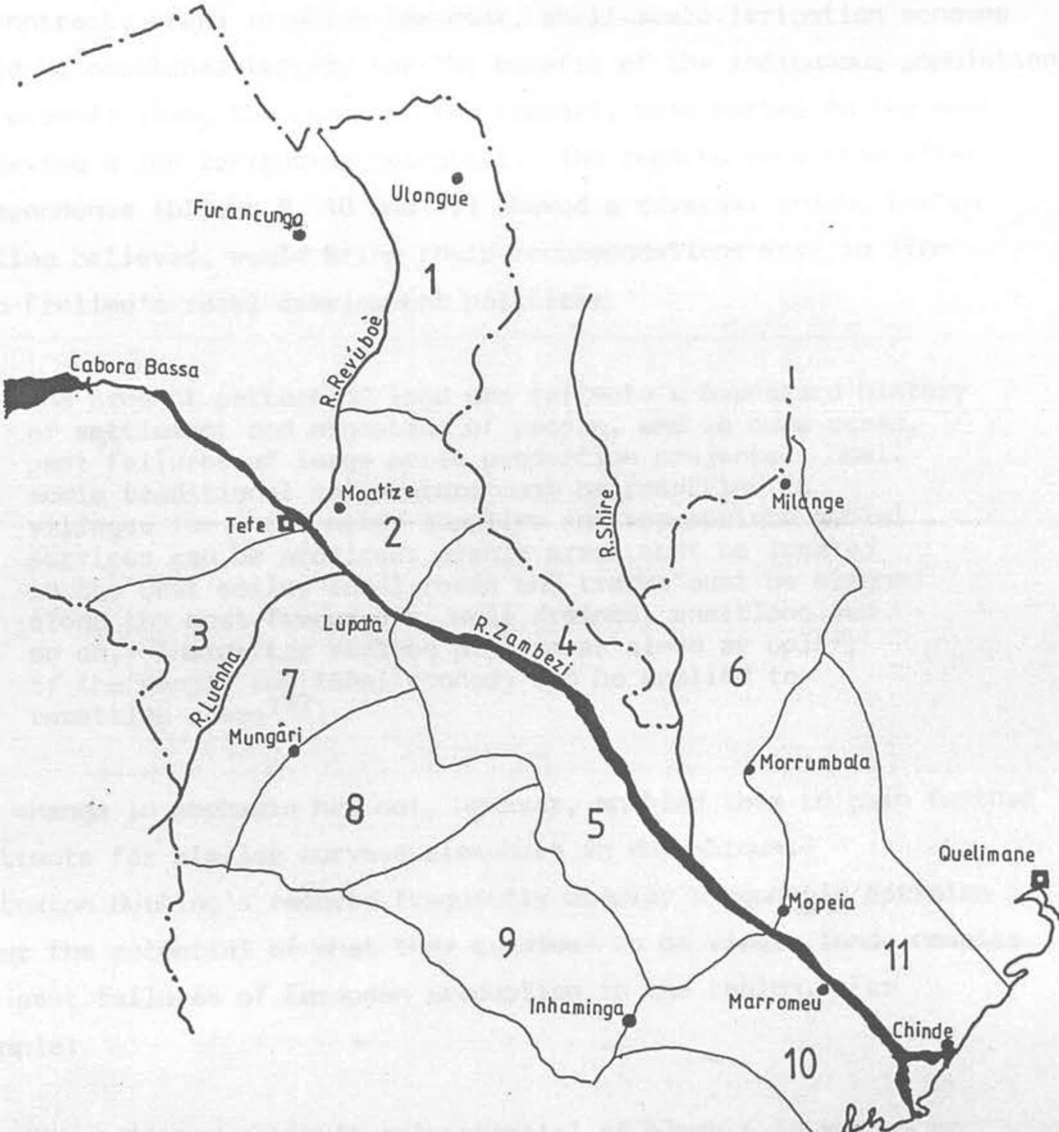
* The group is referred to as 'Loxton Hunting' throughout this thesis.

Figure 9

Division of the Lower Zambezi Valley into 'blocks' for comprehensive mapping of land use potential



1-3 No studies undertaken

4-6 Studies completed by Loxton Hunting 1973

7-8 Preliminary studies only

9-11 Studies completed by Loxton Hunting 1975

b) No attempt was made to map existing patterns of land use or population distribution.

c) The absurdity of attempting to make land use recommendations without reference to social, political and economic factors, or to existing patterns of habitation and land use, is demonstrated in the reports by the marked change of emphasis following independence. In the pre-independence reports (blocks 4, 5 and 6) considerable stress was laid on the potential for estate and plantation agriculture. By contrast, areas in which low-cost, small-scale irrigation schemes could be developed largely for the benefit of the indigenous population, for example along the banks of the Zambezi, were marked on the maps as having a low irrigation potential. The reports published after independence (blocks 9, 10 and 11) showed a reversal which, Loxton Hunting believed, would bring their recommendations more in line with Frelimo's rural development policies:

> The present pattern of land use reflects a haphazard history of settlement and migration of people, and in some cases, past failures of large scale production projects. Small scale traditional cultivators must be resettled in villages for which water supplies and appropriate social services can be provided: arable areas must be located in the best soils: local roads and tracks must be aligned along the most favourable, well drained, positions and so on. Thereafter various programmes aimed at uplift of the people and local economy can be applied to resettled areas[132].

The change in emphasis has not, however, enabled them to gain further contracts for similar surveys elsewhere in Mozambique.

d) Loxton Hunting's reports frequently display a euphoric optimism about the potential of what they consider to be virgin lands despite the past failures of European production in the region. For example:

> The untapped agricultural potential of block 6 is vast - so vast indeed that, as a unit, when fully developed, the region could become a major contributor to the agricultural economy of Mozambique[133].

e) The types of land use considered by Loxton Hunting are largely those employing 'modern' mechanized techniques, the most intensive form of cultivation being suggested as the recommended land use for any given area. The long-term ecological effects of intensive mechanized agriculture, in particular in the alluvial plain and delta region, are not given adequate consideration nor are the possible advantages of adopting less intensive land use patterns. The possibility that salination and drainage problems might affect production, however, was noted.

f) Despite the detail in which Loxtin Hunting's maps and reports were presented the authors acknowledged that much of the information, including climatic and soils data, was not sufficiently detailed for large investments to be undertaken without further investigations. The reports, therefore, made strong recommendations that pilot projects should be established.

g) Pilot projects were also recommended because, apart from sugar cane, there was little experience of irrigated cultivation in the region. The projects would, therefore, allow experimentation with other crops and provide training for those who would continue the operations. Nevertheless, one of the principal recommendations made was that further sugar plantations, similar to the Sena Sugar Estates, should be created at an early stage.

h) Loxton Hunting acknowledged that the success of any agricultural project would depend on a considerable improvement being made in the provision of transport and other services in the region.

3. <u>Navigation Plans</u>: American engineers in the 1950s showed considerable enthusiasm towards the development of inland navigation:

> All the great civilizations of recorded history have been centred around mass transportation by water. (...)
>
> Throughout the entire history of Western civilization, navigable waterways have provided the avenues for community growth. (...)
>
> The history of the development and utilization of our waterways [in the USA] is marked by three distinct periods: First, the development of the rivers for seasonal use of the keelboats, flatboats and rafts and later for the fabulous packet boats; secondly, the period of decline; and thirdly, the rebirth of the waterways system as a mass transportation artery[134].

Such views of the potential for navigation to stimulate economic development in the USA were shared by the Portuguese planners of the MFPZ. As noted earlier, navigation on the Zambezi had been important for the establishment of the earliest Portuguese settlements in the valley and development schemes based on mass transportation by river had been proposed in the nineteenth and early twentieth centuries. The coming of the railway had, however, caused navigation to decline to the point where, by the late 1950s, it had virtually ceased on the river above Mutarara. The MFPZ planners clearly believed that the 'rebirth' phase had been reached and that mass transportation by river would provide the basis for their other development projects in the valley.

The largest bulk of goods requiring transportation would, it was believed, be minerals which would originate from two main areas of deposits; the region north of the city of Tete and the region near Mucanha part of which now lies under the north shore of Lake Cabora Bassa*. Bulk transportation of agricultural and forestry products was also envisaged. Navigation was, therefore, proposed from Cabora Bassa Gorge to the Zambezi's mouth as well as on Lake Cabora Bassa.

In an attempt to increase the project's economic returns it was also suggested that goods from Zimbabwe and Zambia might be transported. For this purpose road or rail links would be provided to ports on Lake Cabora Bassa or at Tete. The initial response of the colonial authorities in these countries was, however, unfavourable when, in 1959, the MFPZ undertook a fact-finding mission[135]; they were informed that the proposed navigation system would be less economic than the existing railway network, it would require new investment in the road or rail links and it would be slower.

This discouraging response does not appear to have reduced the enthusiasm within the MFPZ. For the *Plano Geral*, detailed studies were undertaken of alternative means for transporting 250 x 10^3 t/yr to 3 x 10^6 t/yr of minerals from Mucanha to the coast. Although their calculations indicated that for the smaller totals a railway would

* See Chapter 4 for further details of the plans for mineral exploitation.

provide the cheapest form of transportation it was argued that the river system should be given preference because tonnages were sure to increase. Nevertheless, attention was drawn to some of the technical difficulties which the project would create. These are among the problems which are discussed below:

a) On Lake Cabora Bassa navigation is impeded by strong winds and by large fluctuations in water level. These problems were not discussed in the *Plano Geral* but have been elaborated by the GPZ in a more recent report[136]. Pre-impoundment studies indicated that the reservoir would experience strong winds from a predominantly south-easterly direction. Unless large boats capable of withstanding such conditions could be transported to the reservoir by road, which seems unlikely, they would have to be constructed locally. The main significance of the large fluctuations in water level would be in their effect on the location and design of port facilities. The GPZ report considered drawdown to a minimum level of 311 m (20 m below dam crest) although earlier plans had assumed the minimum drawdown level to be 295 m (36 m below dam crest). Even if port locations were chosen to provide the maximum shoreline slope, the cost of construction of facilities which could operate over such a wide range of reservoir levels would be high. In addition, navigation at the head of the lake would be under riverine conditions since the impounded water would move as much as 100 km downstream of Zumbo at maximum drawdown. The progressive deposition of silt in this region of the reservoir would further increase the difficulty of navigation.

b) Transport past the Cabora Bassa Dam presents particular problems. Three alternative means of allowing loaded barges, of conventional design, to pass the dam were investigated in the *Plano Geral:* a system of locks cut into the gorge, a water slope of the type described by Aubert (1979) or a single hydraulic lift through a large diameter vertical shaft cut through the rock. The last of these was discounted because of the technical difficulties involved in resisting the great hydrostatic pressure at the lower gate and because of the high cost. Of the other two, the system of locks was preferred but was rejected because of the high capital cost (at least 50% greater than the cost of the dam itself) and because the maximum capacity of 6×10^6 t/yr was thought to impose too great a restriction on the future development of the system. As a result the method finally proposed in the *Plano Geral* for by-passing the dam was the use of amphibious barges which could be lifted from the water and placed on bogies moving on a special track.

c) The stabilization of the channel downstream of Cabora Bassa Gorge, either with or without further dams, would be a difficult and highly expensive operation. The details of this are considered in Chapter 5.

d) Probably the most intractable problem in creating the proposed navigation system is that of a suitable ocean port near the mouth of the Zambezi. The technical aspects of this problem were discussed in one of the last GPZ reports to be published[137]. Sand bars prevent access, by all but vessels of the shallowest draught, to the existing port of Chinde or to alternative port locations in one of the other openings of the delta. The possibility of an offshore terminal was considered, but even this does not provide a ready solution since it would have to be located at least 16 km from the shore to obtain the necessary depths for modern bulk mineral carriers. The possibility of using the existing ports at Beira and Nacala was also considered, with the latter being preferred because it allowed more room for expansion. If one of these ports were to be used, however, it would introduce problems in linking with the river navigation system. Vessels capable of undertaking the sea passage to Nacala would require a river channel depth of at least 3 m which would greatly increase the cost of river stabilization works. Alternatively, if barges with a draught of, say, 1.5 m were to be used on the river, provision for transhipment to coastal vessels would be required and again introduce additional costs and journey times. Use of a rail link from Mutarara to Beira or Nacala was considered but if a partial rail solution were contemplated it would probably be preferable to use rail transport over the entire distance. Such a solution would obviate the need for river navigation.

The GPZ reports cited above indicate the continuing commitment of the Portuguese planners to the idea of river navigation up to the end of colonial rule. Further technical alternatives were considered including a mineral railway or cableway, over part of the distance, in particular past the dam, a 'mineral pipeline' over the whole distance to the chosen port[138], and the containerized barge system known as 'Lash' (Lighters aboard ship)[139]. In each case, however, the economic viability depended on a very rapid expansion of mineral extraction and trade.

Developments in the Zambezi valley since independence

1. The Cabora Bassa Project: The political significance of the Cabora Bassa Project was dramatically changed by the fall of President Caetano following a left-wing military coup d'etat in Lisbon eight months before the date scheduled for the closure of the dam. Immediately following the signing of a general Agreement in Lusaka, in September, 1974, between representatives of Frelimo and the new authorities in Portugal guerrilla attacks on the project area ceased. Construction work was then supported by Frelimo. Indeed, the interim Prime Minister of Mozambique, Joaquim Chissano, speaking in Songo:

> castigated some of the labourers for not working overtime, and exhorted the rest to surpass all previous efforts to finish the dam on schedule for the state of independent Mozambique[140].

Details of the Lusaka Agreement were elaborated in discussions between Portuguese and Frelimo delegations which lasted from late January, 1975, until Independence Day, 25 June, 1975. The future status of the Cabora Bassa Project featured prominently in these negotiations[141]. Western governments and financial institutions which had invested heavily in the project were as concerned about the agreement as was Portugal which had guaranteed their loans. A mutually acceptable solution was found in the creation of a Portuguese registered operating company, Hidroeléctrica de Cahora Bassa (HCB), which would be responsible for the generation of electrical power, the sale of that power to Escom and the scheduled repayment of the investments. Under such an agreement Escom was prepared to honour the original contract to purchase power*.

HCB was granted a concession to operate the project, with the status of a public utility, for an agreed period dependent on the loan repayment schedule. The terms of the concession are set out in the *Contracto de Concessão do Aproveitamento de Cahora Bassa*. The provisions of this document govern financial aspects, the generation and supply of electrical power, the status and conduct of HCB's staff and the

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* Further details of the terms under which the HCB operates and the financial aspects of the agreement with Escom are given in Chapter 4.

number of foreign personnel which may be employed at any one time. In addition, the following two provisions are of particular interest to the present study:

a) Article 14 states that HCB is required:

> to organize operating schedules for the hydroelectric station and for the utilization of water stored in the reservoir and to undertake rainfall and hydrological measurements, as determined for them, supplying the authorities with this operating information and statistical data as required of them by the regulations in force. (writer's translation)

This single article governs HCB's obligations in the operation of the project in all respects other than power generation. Its general terms have led to confusion, and consequently, to disputes between HCB and various government agencies. This is particularly true as regards flood alleviation and flood warning. HCB has been accused of failing to provide adequate flood warning, and of failing to adopt operating procedures which would minimize the flood risk. HCB's Directors replied by demanding better access to hydrological information both upstream and downstream of the dam.

The control of aquatic vegetation provided another area of dispute. The HCB position was that the Mozambican authorities were obliged to take any steps necessary to prevent weed infestation from threatening power production, including the funding of a commercial weed control unit employing foreign expertise. This was contrary to the views of Government officials who believed that it would be sufficient to establish a monitoring unit, within the Ministry of Agriculture, and accused HCB of exacerbating the problem by their failure to ensure proper maintenance of the two weed control booms which protect the turbine intakes.

In both instances HCB appeared to be using the disputes to clarify and, if possible, broaden its sphere of responsibility. Proposals were also put forward by HCB for a more active participation in the management of fisheries, reservoir navigation, utilization of the shore line and scientific investigations around the reservoir[142].

b) Provisions were made which governed the development of further projects and, specifically, the proposed North Bank Station:

The undertaking of additional investments by the concessionaire, for the purpose of increasing the installed capacity of the Cabora Bassa Hydroelectric Project will depend on previous authorization by the Government of Mozambique. (Article 19, writer's translation)

Article 2, however, states that, subject to such authorization, the construction and operation of the North Bank Station would be included within the terms of HCB's present concession*. In this respect, at least, HCB could expect to increase its responsibilities should this project proceed. These provisions have, therefore, assumed considerable significance since July, 1980, when the Government invited international consortia to submit initial tenders for the construction of the North Bank Project. (For details see Appendix 5)

The present attitude of the Mozambican Government to the Cabora Bassa Project is determined by its desire to transform it from a symbol of colonialist and capitalist exploitation to a symbol of independent self-determination - the resources of Mozambique working for the people of Mozambique. Since the present agreement to sell power to the RSA does little to further that objective the authorities have sought to derive other benefits from the project and to publicize these as widely as possible. In a major speech in August, 1979, President Machel said:

> We cannot irrigate without energy. The electrification of the Centre-North and of the South of our country is a fundamental condition needed to enable us to respond to the needs of agriculture. We must tame the 'white elephant' which CAHORA BASSA is. This 'elephant' must give our agriculture and industry the ivory of electrical energy and irrigation ... The next decade will demand the entry into operation of the North Bank Station and the building of numerous dams for irrigation and electrification[143].

2. <u>Other developments in the Zambezi valley</u>: None of the other hydroelectric projects proposed for the Zambezi valley are under active consideration. By contrast there have been some important changes affecting agricultural production since independence: co-operative production has been stimulated, albeit on a relatively small scale[144];

* Whether this would also apply to other projects on the Zambezi downstream of Cabora Bassa was not specified.

production in the family sector has been encouraged both of food crops, such as maize and millet, and of commercial crops, such as cashew nuts and cotton[145]; and a number of new projects have been started, including small-scale poultry production in parts of Quelimane District[146] and around the city of Tete. The biggest changes have, however, been in the state sector which is based on former Portuguese and foreign owned farms and plantations. In Angônia, for example, an agro-industrial company produces maize, fruit, potatoes and other vegetables[147]. A new administrative commission was appointed in, May, 1976, to manage the lands of the Companhia do Boror after the former proprietors had fled the country[148]. The commission is now attempting to re-establish coconut and livestock production at pre-independence levels[149].

The case of the Sena Sugar Estates merits closer study. Since the 1930s Sena Sugar Estates Ltd has owned two plantations, one at Luabo on the north bank of the Zambezi and the other at Marromeu on the south bank. Both plantations are served by processing factories and the total area planted has been increased to about 24 000 ha. From 1930 to 1960 the average annual employment on the two plantations was 30 000, the majority of whom were migrant workers who lived and worked under extremely harsh conditions on six month contracts[150]. In the early 1960s, international pressure compelled the Portuguese authorities to revise its labour recruitment policies, which had included the use of various forms of coercion. This intervention led to the Sena Sugar Estates being threatened by labour shortages. In response, the management attempted to decrease its labour demand by mechanization and by providing permanent employment for a smaller, settled, labour force. The recruitment of seasonal labour, however, continued.

During the period of transition to independence labour suddenly became more plentiful and as a result the company decided to forego previous guarantees of employment and to rely solely on casual labour. This policy together with poor economic management and moves by the proprietors which were interpreted as attempts to obstruct the commissioning of new equipment led to accusations of 'economic sabotage' against the company. The resulting conflict with the Government led to State intervention in August 1978[151]. The two plantations retain considerable economic importance for Mozambique. They comprise approximately half of the total area of sugar plantation in the country. The capacity of the two processing factories, as reported in 1979, was an annual output of 180 000 t and the total employment provided by the plantations and factories was 12 000 [152].

Agricultural plans for the Zambezi valley include proposals to implement various large-scale irrigation projects in the near future. In the documents for the 3rd Party Congress, which listed planning objectives for the period 1977-80, the Frelimo Central Committee resolved:

> To begin immediate studies with a view to construction of irrigation systems in the Zambezi valley[153].

In September, 1981, it was reported that studies were in progress for five projects covering a total of 210 x 10^3 ha in the regions of Marromeu, Mopeia, Caia, Mutarara* and Morrumbala[154]. The projects range in size from 30 x 10^3 ha to 60 x 10^3 ha and all lie on the alluvial plain in situations where irrigation could be provided from the Zambezi. It should be noted that each project is larger than the combined area of the existing plantations of the Sena Sugar Estates. Looking further ahead, the plans appear to be even more ambitious. A number of officials in Maputo envisaged a total irrigated area on the alluvial plain of 1.5 x 10^6 ha with additional irrigation over large areas of the Luia, Revúboè and Luenha basins. Such plans appear to derive directly from those contained in the *Esquema Geral* and the *Plano Geral*.

Other plans for the Zambezi valley include a rapid expansion of coal production at Moatize, this is considered further in Chapter 4.

The MFPZ's navigation plans have not been neglected since independence; the main features were discussed in an article (prepared by the DNA), which appeared in a technical journal[155]. Olivier[156] attempted to re-awaken interest in the Zambezi as a transport route by suggesting

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* The Mutarara project is, almost certainly, located on Ilha de Inhangoma much of which was naturally irrigated by floods from the Zambezi before the construction of Kariba and Cabora Bassa Dams.

that the use of hover barges would create a rapid, economic system without the need to undertake extensive channel modifications. His concept was directed towards the provision of an alternative transport link for Zambia, Malawi and, presumably, Zimbabwe. Such a solution to transport problems implies relatively low density/high value cargoes rather than the low value bulk mineral cargoes envisaged by the MFPZ planners. Mitchell (1981) also discussed the possible benefits to Zimbabwe of a transportation system along the Zambezi, and recommended that technical and economic aspects of such a scheme should be more thoroughly investigated with reference to the proposal to build a dam at Mpata Gorge.

The Mozambican authorities now appear to be moving towards a less ambitious approach to the planning of transportation in the region. For the export of coal from Moatize the emphasis is now on improving the rail link to Beira and the cargo handling facilities at that port[157]. Transport links with Zambia, Zimbabwe and Malawi are also being discussed as one of the priorities of the SADCC[158]. Here, too, the emphasis, at present, is on improving existing facilities, in particular the rail links and ports, rather than on creating alternative transportation systems. Of the MFPZ's plans for navigation along the Zambezi, only one aspect is currently being implemented - navigation on Lake Cabora Bassa. Yet even this project appears to be on a fairly small scale; no details of the role of the shipping company recently formed with Bulgarian aid[159] have been published but it is unlikely that it will be required to transport any large quantities of cargo in the foreseeable future.

The present chapter has provided a general introduction to the factors which have shaped social and economic change in the Zambezi basin since the arrival of the first European settlers. Although numerous proposals have been made for the expansion of European agriculture and the development of river navigation in the basin few have been implemented. Much of the basin still lacks an adequate system of transport and communications, few areas have been left with a sustainable form of mechanized or irrigated agricultural production. Traditional agriculture has, nevertheless, suffered considerable disruption as a result of the continuous demand for labour under the colonial regime and, more recently, the changes which have been brought about by the creation of the large hydroelectric projects (see Chapter 6). However, earlier proposals for the spectacular development of the lower Zambezi, based on agriculture and navigation, continue to exert an influence over the authorities in Mozambique.

The demand for hydroelectric power has had a dominant influence over the development of all parts of the basin for much of the present century. The Kariba, Kafue and Victoria Falls projects, together with a number of smaller projects, were built solely to meet that demand. For the Cabora Bassa Project, despite initial suggestions that the dam would bring multiple purpose benefits, the production of hydroelectric power became the dominant factor in its implementation and has remained so in its subsequent operation. The discussion of these projects in this chapter has highlighted some important technical and political aspects of the regulation of the Zambezi, and, in particular, of the Cabora Bassa Project. Many of these aspects have a bearing on the development of the remaining chapters in this thesis.

C H A P T E R 3

HYDROLOGICAL CONSIDERATIONS IN THE DESIGN AND OPERATION OF THE CABORA BASSA PROJECT

The techniques of engineering hydrology

Hydrology, in its broadest sense, refers to the science of water but, although water has been regulated to meet human needs since prehistoric times, the theoretical basis of hydrology has only been established relatively recently. Ancient works were designed from accumulated practical experience, some of which was gained at considerable cost[160]. Although the Roda gauge on the Nile provides a record of peak annual river levels for a period of over a thousand years few attempts were made to measure hydrological phenomena (precipation, evaporation, river discharge) before the seventeenth century[161]. In Britain, the first book on hydrology was published in 1862 and the first systematic river discharge records were begun at about the same time. Thus, few systematic river records cover a period of more than a hundred years.

Linsley (1967) provided the basis for a simplified history of the development of surface water hydrology from the late seventeenth century until the present. The period until 1930 he termed the era of empiricism when lack of adequate data prevented the development of rational theories. That development was achieved during the period from 1930 to 1955 which Linsley termed the period of correlation. Since 1955 considerable emphasis has been placed on the analysis of hydrological processes by numerical modelling which is now largely accomplished with the aid of electronic computers. This period has, therefore, been termed the computer era.

Bruce and Clark (1966, p1) suggest that it is only since about 1940 that it has been possible to make practical use of meteorological data in the design of water resources projects. In the ten or twelve years after 1955 a number of major texts on hydrology were published which have been widely used by engineers concerned with the development of water resources[162]. In 1964, an International Hydrological Decade was initiated, under the auspices of UNESCO, with a view to improving the worldwide collection and exchange of hydrological data. The Institution of Civil Engineers in London (ICE) marked the end of the decade with a special conference on engineering hydrology[163]. The contributions to this conference indicated some recent areas of development, particularly the study of applied hydrology by scientists and engineers in the UK. A number of the points raised in general discussion are of interest. Various speakers[164] suggested that the heavy bias of the conference papers towards British problems and experience reflected a more general bias amongst researchers in the UK away from the special problems of applied hydrology in other parts of the world. This was despite the fact that the value of overseas contracts for water resources projects being undertaken by British firms was two or three times greater than for projects in Britain. There was also some discussion about the practical application of theoretical advances: for example, W L Jack suggested that the conference had shown 'a healthy scepticism of the escalation of mathematical modelling' and that a pre-requisite for any improvement in hydrological analysis was an improvement in the collection and publication of 'good quality data'

During the 1970s, a large number of hydrologists and engineers in Britain became involved in the preparation and interpretation of a major report on flood evaluation - the *Flood Studies Report*[165]. The work behind the report was intended to provide nationally accepted techniques for the estimation of floods, from the available hydrological, meteorological and topographical information, for application throughout the UK including areas for which the available river discharge records are, by themselves, inadequate. The preparation of the report entailed the collection of large quantities of data which were used both in the preparation of 'regional envelope curves', for use in areas of inadequate data, and in the development and calibration of new analytical techniques and numerical models. The concept of a physical upper limit to precipitation, the probable maximum precipitation (PMP), was given prominence. Techniques for the analysis of flood hydrographs were also developed by means of which values of probable maximum flood (PMF) could be determined, at any point on a river system, from previously calculated PMP values. Alternative methods of analysis, including the statistical analysis of river discharge records, were also described in the report.

Five years after the publication of the *Flood Studies Report*, a conference was organized by the ICE to discuss experience in the practical application of the report and consider new developments in the evaluation of floods. As in the conference at the end of the International Hydrological Decade, cited above, a number of speakers were concerned about the heavy bias in the report towards British conditions and experience although, as Sutcliffe[166] pointed out, the report was not specifically intended to be applicable overseas. Hall, referring to Linsey's description of the historical development of hydrological methods, suggested that in the estimation of floods the availability of computer facilities had made less impact than in other branches of hydrology and that:

> the influence of the era of empiricism and the era of correlation are still very evident in present-day practice[167].

This, he continued, was particularly true in developing countries which lack 'an adequate data base'. An illustration of the difficulties encountered in sub-Saharan Africa was provided by Lynn[168] from his experience of a project in western Nigeria.

One of the principal areas in which the *Flood Studies Report* has been applied is in the design and operation of reservoir spillways to prevent catastrophic dam failures. British engineering practice, since the 1930s, had been based on an interim report made by a committee of the ICE in 1933 . That report set out design procedures based, primarily, on the analysis of existing river discharge records which were to be extrapolated to provide an adequate factor of safety. In the event, a wide variety of design practices came to be adopted, many of them based on the empirical formulae of individual consultants. To achieve wider concensus, the adoption of standard procedures was proposed in a report prepared by the ICE (1978) following the publication of the *Flood Studies Report*. This report proposed that spillway design be based on the theoretical PMF as calculated from the *Flood Studies Report* or, where the reservoir presented less hazard, on the PMF reduced by a suitable factor. A number of engineers, however, held that these procedures, which involved scaling down from a theoretically determined maximum, appealed less to their engineering judgement and appeared to be less conservative than the earlier procedures[169]. A further area of discussion was the report's suggestion that the results of economic studies could, in certain circumstances, be used in the design of reservoir spillways. The suggestion had been made, in an earlier discussion paper, that economic analysis be given priority in the design of most reservoir spillways. This was, however, given less emphasis in the final report following suggestions that, in many cases, the results of economic evaluations of the damages which might result from catastrophic floods were unreliable and subjective[170]. Lying behind much of the unease expressed about economic analysis and, indeed, of any form of categorization of dams according to risk was a more fundamental issue. Many engineers were of the opinion that unless legally accepted guidelines were produced the design engineer would bear the responsibility for assessing the level of risk and that if, in a particular case, he chose to adopt a design flood less than the PMF, he would be culpable should excessive damages result from a catastrophic flood[171]. British engineers remain divided about a suitable method for incorporating the statistical analysis of risk into their design of flood spillways. A number have advocated an economic approach similar to that used in the USA which may include the placing of an economic value on the risk of human fatality[172].

The interest in short-duration flood hydrology in Britain arises from the considerable hazard posed by floods in a relatively densely populated country which is heavily cultivated and urbanized, and in which there are numerous old reservoirs of small capacity. Other hydrological factors which are less important under British conditions have been studied more extensively in other parts of the world, particularly in the USA. These factors include the operation of multiple purpose reservoirs and multiple reservoir systems, the operation of large capacity reservoirs, the hydrology of arid and semi-arid regions, the hydrology of regions which experience tropical or seasonal rainfall or catchments in which substantial changes in the natural vegetation are taking place, the hydrology of large natural floodplains and the problems posed by heavy evaporation losses. The techniques which have been developed for studying some of these are considered in the rest of this section.

The basic tool which has been developed to assist in the operation of reservoirs is the rule curve. It is most commonly applied to single hydroelectric reservoirs which experience a seasonal pattern of inflow[173].

but combined rule curves for multiple reservoir systems have also been used[174]. In general, an energy, or lower, rule curve indicates the minimum reservoir levels which can be tolerated throughout the year if sufficient water is to be stored to guarantee the required energy (or other, primary) output. Surplus capacity, represented by reservoir levels below the maximum storage level and above this lower rule curve, may either be used to store water for additional outputs, such as increased power production or irrigation releases, or it may be held vacant in order to regulate flood inflows. Energy rule curves are generally established by simulating the operation of the reservoir for a selected critical series of inflow data - either the data from the driest year on record or a synthetic data series representing the most severe conditions which the hydrologist anticipates. Such rule curves serve only as approximate guides to reservoir operators; special circumstances, such as the need to undertake maintenance work on discharge gates, or additional information, such as a forecast of above average inflows, may cause the operator to deviate substantially from the established curve. With more complex inter-connected reservoir systems, and where there are facilities to provide rapid access to hydrological and meteorological data from all parts of a catchment, frequent adjustments may be made to reservoir discharges in order to optimize outputs in a way which would be impossible simply by strict adherence to the rule curves. TVA engineers make such adjustments daily or, sometimes, more frequently.

In many reservoirs an upper, or flood, rule curve is also constructed. Such a curve is required where the discharge capacity of the dam is insufficient to pass the full design flood discharge, some of which will require temporary storage to prevent over-topping of the dam. Where the critical flood is of short duration and might occur in any season, as in most small catchments in temporate climates, a single limit, the normal maximum storage level, is applied throughout the year. Where floods are seasonal, and where the possibility arises that inflows will exceed dam discharge capacity over a long period, a flood rule curve must be used. The curve specifies the maximum reservoir levels, through the year, which can be tolerated if sufficient storage capacity is to be reserved to prevent over-topping the dam. In general, the principal feature of the flood rule curve will be a requirement to draw down the reservoir to a specific level, by a particular date each year, in advance of the major flood season. The maximum levels of the flood rule curve should be strictly adhered to since to neglect them may result in extensive damage to, or even catastrophic failure of, the dam. The flood rule curve is calculated by simulating the operation of the reservoir taking appropriate values of the design flood as the input data. The ICE (1978) report provides procedures for the selection of suitable values of the design flood under various conditions.

Rule curves may need revising, from time to time, as new data or techniques of analysis become available or as the demand for the project's principal output changes. Numerical models, which simulate the operation of the reservoir, are frequently used both to assess the effects of such changes and to optimize the project's operation for primary and secondary outputs. Young (1968) provides an example of this type of optimization exercise for a reservoir whose required primary and secondary outputs are flood control and low flow augmentation, respectively. The major problem in undertaking any such simulations is how to take account of the natural stochastic variations in reservoir inflows. For example, a project designed to give certain irrigation benefits solely on the basis of the mean annual inflow may experience, say, three years out of ten when there is insufficient water to provide these benefits. Yevdjevich (1965) has provided a useful introduction to the methods which may be used to account for stochastic variations in annual inflows for the design of independent reservoirs. The methods include empirical analysis, data generation and analytical methods. Empirical analysis is the simplest and requires that recorded inflow data are studied to identify the median year, and other years of selected frequencies, which are then used as inputs in a reservoir simulation model. Alternatively, the whole series is fed into the model and a statistical analysis performed on the results. Data generation is used to extend a short series of recorded data with data which exhibits similar statistical properties. Fiering(1965) provided a realistic assessment of the limitations and applications of this technique. Analytical techniques involve fitting a mathematical curve to the recorded data series and using this curve as the basis for analysis of the reservoir's operation. Analytical methods are generally considered to be more accurate and the *Flood Studies Report* placed considerable emphasis on them in the estimation of floods. It should be noted, however, that the accuracy of any of these methods depends on the length and accuracy of the existing data records. Data generation and analytical methods appear to offer techniques for obtaining greater accuracy when using short data records but they can only do so by making assumptions about the statistical characteristics of the natural data - assumptions which are not necessarily valid. The likelihood of error may, however, be reduced by using additional data from adjacent or similar catchments when determining these characteristics.

The reservoir simulation models referred to above constitute a simple form of systems analysis. The input to the system is the reservoir inflow data, the system is the reservoir and dam with its particular storage and discharge characteristics and the output is the dam discharge data which, for a hydroelectric project, may be expressed in terms of power output. The numerical analysis is based on a simple mass balance for the system using discrete time intervals which may vary from less than an hour to more than a week, depending largely on the capacity of the reservoir and the area of its catchment. The time intervals chosen for the analysis may also depend on the quality of the input data and on the purpose for which the analysis is being undertaken.

Even in a simple system, such as that outlined above, there are many factors which could influence the results of the analysis. In many underdeveloped countries, the lack of accurate long-term hydrological records may make it very difficult to derive a reliable set of input data. Furthermore, even where reliable data are available, existing records rarely provide a basis for assessing the possible effects on the future pattern of reservoir inflows of changes in catchment characteristics or climatic factors. Evaluation of the parameters of the system itself generally presents fewer difficulties. The relationship between storage capacity and reservoir level can be determined provided that accurate maps of the area were made before the reservoir was impounded. Nevertheless, this relationship will change appreciably should rapid siltation of the reservoir occur. For the purposes of analysis, evaporation and seepage losses from the reservoir may be taken as negligible. But, in cases where the losses are believed to be too large to neglect, accurate assessment of their magnitude is extremely difficult. For a given set of system parameters and inputs the calculation of outputs is straightforward. Nevertheless, if output values are required in terms of the quantity of hydroelectric power generated, further relationships must be included in the analysis to define the turbine operating characteristics. In the analysis of a reservoir's response to flood inflows, the discharge characteristics of the dam's spillways and gates must also be specified. For a reservoir which is operational, the system analysis may be conducted in the reverse direction as a means of calculating actual (ungauged) inflows from recorded reservoir discharges and levels or, where inflows, outflows and reservoir levels have been accurately determined, of providing estimates of seepage and evaporation losses. Olivier (1972) notes a possible source of error in this type of analysis:

> ... in flood routing operations where inflow is calculated from changes in reservoir level, and where the reservoir is of appreciable length ... the changes in reservoir level must be measured at the null point of oscillation of the lake to ensure seiches do not lead to spurious flood predictions. (p64)

The analysis of single reservoirs may be extended to inter-connected reservoir systems. Amongst the more interesting published accounts of the analysis of multiple reservoir systems is that described by Speers (1976) for the operation of the hydroelectric stations at thirty-eight dams on the Columbia River. Speers envisaged a radical change, before the end of the century, in the pattern of hydroelectric demand from the system: from that of base-load operation, for which the project's were designed, to that of providing peak power to supplement base-load thermal and nuclear power stations. The analysis enabled the hydrological implications of such a change to be considered and provides the basis for calculating a completely new set of operating procedures. Clearly, the analysis of such a complex multiple reservoir system involves a considerable amount of numerical analysis which could only be undertaken with the aid of an electronic computer.

The system may also be extended in other ways, each of which, however, results in numerical models of greater complexity. The most common extension considered is that of including in the system not only the reservoir but also the whole of its catchment area. Since the records of meteorological data required as inputs to this enlarged system are generally more reliable and cover longer periods than the records of river flow required for analysis of the single reservoir system there are certain advantages to be gained through such a modification. On the other hand, the whole hydrological cycle within the catchment is, in effect, included within the system[175] with the reservoir operation comprising only one small sub-system. This inevitably increases the complexity of the analysis. For example, a rigorous analysis would have to take account of evapo-transpiration effects, the interaction between surface water and ground water, areal differences in the distribution of rainfall over the catchment and time factors related to runoff, including the effects resulting from temporary storage in river channels, floodplains and natural lakes. The accurate modelling of such characteristics demands a considerable amount of data and information from the catchment and may, in some cases, require further studies to be undertaken of the hydrological processes involved. Since, in most instances, it is unlikely that such information would be readily available for a catchment where river discharge records are considered to be inadequate, the direct applications for such a model are limited. In practice, hydrologists develop hybrid models which are appropriate to the available information and data. Thus, where river discharge records are available for part of the catchment, the correlation between meteorological and hydrological data for gauged tributaries may be investigated to provide simplified runoff relations which are then assumed to apply over the whole catchment. Alternatively, if a limited number of hydrological records are of significant length for detailed analysis, correlations between such records and shorter records may be investigated with a view to using the relationships obtained in extending the length of the shorter records. In some cases random number generation may be used in association with such techniques to produce more realistic stochastic variations in the river discharges generated by the model. Numerical models, such as these, are widely applied in the investigation of many of the hydrological questions referred to above.

A further increase in complexity results when attempts are made to include biological and environmental relationships and responses in the analysis. The present state of the art in such 'ecological modelling' may be judged from a study of the papers edited by du Bois (1981). Many of the models presented would be applicable to various, aspects of stream regulation. At the present time, organic and inorganic pollution are the principal areas of interest but it is commonly believed that satisfactory ecological models can be developed to investigate changes in the vegetation of reservoir catchments, the effects of reservoir operation on fish communities and downstream effects of river regulation including the effects on floodplains and estuaries. One of the principal problems with such models, and, indeed, with all numerical models, is the difficulty of assessing their level of accuracy. Such assessments are rarely even attempted. Fedra (1980) showed how such assessments might be made by sensitivity analysis. The probable error in each piece of input data and in each assumption about the system's characteristics was assessed and, by repeated analysis of the system, the effects of these errors were studied in terms of the probability distribution of the output data. Clearly, such analysis again increases computation time by a considerable factor.

The system could be extended still further, for optimizing the design of projects, to include economic factors as well as social and political factors related to the development of the available water resources. Consideration of such a broad system has been strongly advocated in various of the publications by G F White and in the paper by Webb and Hufschmidt cited in Chapter 1. Considering the present state of the art, the simplifications and approximations which would be necessary to analyse such a comprehensive system wholly by numerical methods, particularly for river basins in underdeveloped regions, would almost certainly render the results less reliable than those based largely on 'subjective' engineering judgement.

The study of hydrological phenomena in Africa

A considerable number of hydrological studies have been undertaken in various parts of Africa[176]. No attempt will be made here to provide a comprehensive review of this literature but a number of the more important areas of investigation, particularly those of immediate relevance, are considered.

A large number of studies have been undertaken to investigate the runoff characteristics of small catchments under tropical vegetation, both natural and cultivated, particularly in East Africa. The best known work is probably that of Pereira[177] which began in the 1950s. Other published studies from East Africa include the estimation of floods in small catchments whilst in various areas, including Zambia, attempts have been made to assess the behaviour of large ungauged basins from studies of small catchments[178].

Of the major river basins in Africa, the Nile has been the most intensively studied by hydrologists. The long period for which records are available has enabled hydrologists to consider in detail the idea of long-term storage and regulation, and also provided the necessary data for the important statistical study by Hurst (1951) from which the concept of the 'persistence effect'* in river discharges and other natural phenomena originated. The climatic cycles which give rise to this effect have been studied in other parts of Africa from records of the fluctuations in the levels of natural lakes, see, for example the study of Lake Nyasa (Lake Malawi) by Cochrane (1957).

Although a large number of hydrological studies have been undertaken in the design of reservoir projects in Africa the analyses have generally been relatively simple and have been restricted by a lack of adequate data. Van Cauwenberghe (1960) provided a general review of the problems of designing and operating hydroelectric reservoirs in the tropics with particular reference to projects in the Katanga region of Zaire. He identified, as potential problems, rapid siltation and the calculation of the probable reservoir yield in dry years. The calculation of minimum yields is more difficult in areas outside the equatorial belt, where rainfall is generally confined to one season, or in areas where the mean annual rainfall is low, because, in such areas, variability of rainfall from year to year tends to increase[179]. Olivier (1969) made reference to computer studies which indicated the large differences which occur in reservoir design parameters to achieve the same degree of river regulation in different basins. The studies showed that, in order to provide a

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* Hurst showed that individual events do not occur randomly in nature but that there is a tendency for them to occur in groups; for example, a series of wet years is followed by a series of dry years.

safe yield of 80% of the mean annual runoff (with a recurrence interval of 50 years), reservoirs on the Vaal would require a storage capacity 200% of the river's mean annual runoff whereas, for the Blue and White Niles, the figure would be only 10-40%. Attempts have been made to devise general formulae for the prediction of reservoir yield in particular areas; for example, a set of relations produced by Mitchell (1965), for reservoirs in Zimbabwe, was used in the assessment of the country's water resources undertaken by the Ministry of Water Development (1972).

The lack of adequate hydrological data has proved a major problem in the design of many reservoir projects in Africa including some of the largest. Abiodun (1973) indicated that the inflows to Lake Kainji in Nigeria had, in the first few years of the project's operation, been smaller than those anticipated in the pre-impoundment hydrological studies. A similar short-fall was noted by Kumi (1973) for the Volta River Project in Ghana. In both cases the hydrological records were not sufficiently long to show whether the drier inflows were likely to be a short-term or long-term phenomenum.

Numerical models for use in areas in which hydrological data are inadequate have been developed in the Hydrological Research Unit of the University of Witwatersrand. The model by Pitman (1973) uses meteorological data, together with various coefficients which are related to particular catchment characteristics, to generate monthly river discharge data. Recorded discharges, where available, are used to improve the calibration of the model. This model appears to be relatively simple to use and to have wide application; it provided the basis of a study of inflow data to Lake Kariba undertaken by the CAPC in the late 1970s.

In the Zambezi basin the principal hydrological investigations which have been undertaken have been related to the larger hydroelectric projects - Cabora Bassa, Kariba and Kafue. From a hydrological point of view the Kafue Project is the most complex of the three. The discharges of the Kafue are considerably smaller and show greater inter-annual variations than those of the Zambezi, although the seasonal fluctuations are smaller. In addition, there are few suitable reservoir sites in the Kafue basin. The FAO *Multipurpose Survey of the Kafue Basin* (1968) contained a detailed report on climatology and hydrology (Volume 3). Further studies were undertaken, from 1967 to 1971, by the Swedish engineering consultants, SWECO, for the design of the hydroelectric project and, more recently, the Dutch constultants, DHV, have undertaken a specific study of the hydrology of the Kafue Flats[180]. This last study entailed the use of a rather complex numerical model* to simulate the flow of water through this vast floodplain and the evaporation losses which occur there.

Hydrological studies of the Cabora Bassa Project

For almost the entire period from 1956 to the present some form of hydrological study of the Cabora Bassa Project has been in progress. The results of these studies, published in numerous reports, have led, over the years, to markedly different conclusions about the characteristics and potential of the project. Such differences arise from the methods of analysis, available data and operating assumptions on which the studies were based. The Portuguese firm of consulting engineers Hidrotécnica Portuguesa was closely associated with all hydrological aspects of the work of the MFPZ/GPZ and, as a result, acted as consultants for all the major studies published prior to 1975.

The earliest studies of the hydrology of the Zambezi at Cabora Bassa were estimates of its hydroelectric potential. The estimates published by Manzanares (see Appendix 4) and in the *Relatório Preliminar*, 3, were based on estimated values for the mean annual discharge of the river and the mean gross head, together with an approximate relationship for the efficiency of generation.

The study published in 1961 in the *Esquema Geral*[181] was not, primarily, concerned with energy potential but with the project's capacity to regulate the Zambezi for navigation downstream. A simple numerical model was developed which simulated the operation of the reservoir by calculating the change in the volume of water stored from the difference between the reservoir inflow and outflow in time intervals

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* At the time of the study Zambia did not possess computer facilities which could have handled such a model.

of one month (a monthly water balance model). The analysis was conducted on two extreme sets of hypothetical inflow data: a critical two year dry period (probability 1 in 100 years) and a year containing the estimated design flood. Instead of reservoir operating rule curves, the study recommended the use of a single target reservoir level (310 m on 1 November each year) which would provide the required regulation of discharges over the critical dry period as well as enabling the reservoir to control inflows with the magnitude of the design flood*. An approximate value for the project's guaranteed energy potential was obtained from the numerical model using values for the mean regulated discharge and the mean reservoir level during the critical dry period.

The studies for the *Plano Geral*[182], published in 1965, led to a more elaborate numerical model and sought to improve the quality of the inflow data. Again, the regulation of discharges for navigation was considered to be the primary objective and, as before, two extreme cases were used to provide the hypothetical input data required for the simulation: the design flood and a single critical dry year of probability 1 in 20. From these simulations two operating rule curves were produced, see Figure 10a. For reservoir levels between the two curves the required constant discharge could be maintained; for levels above the upper curve additional (flood) discharges would be required; and for levels below the lower curve discharges would have to be reduced. A rudimentary calculation of energy potential similar to that in the *Esquema Geral* was again undertaken.

Two short reports on energy potential[183] published after the *Plano Geral* do not appear to have been based on an improved method of calculation. The source of an increased estimate of the project's guaranteed energy potential, in the second report, was not explained.

Further attempts to improve the quality of the inflow data together with various amendments made to the reservoir system parameters resulted in the need for a new study to re-evaluate the upper rule curve and the capacity of the dam's discharge gates. The study has been described

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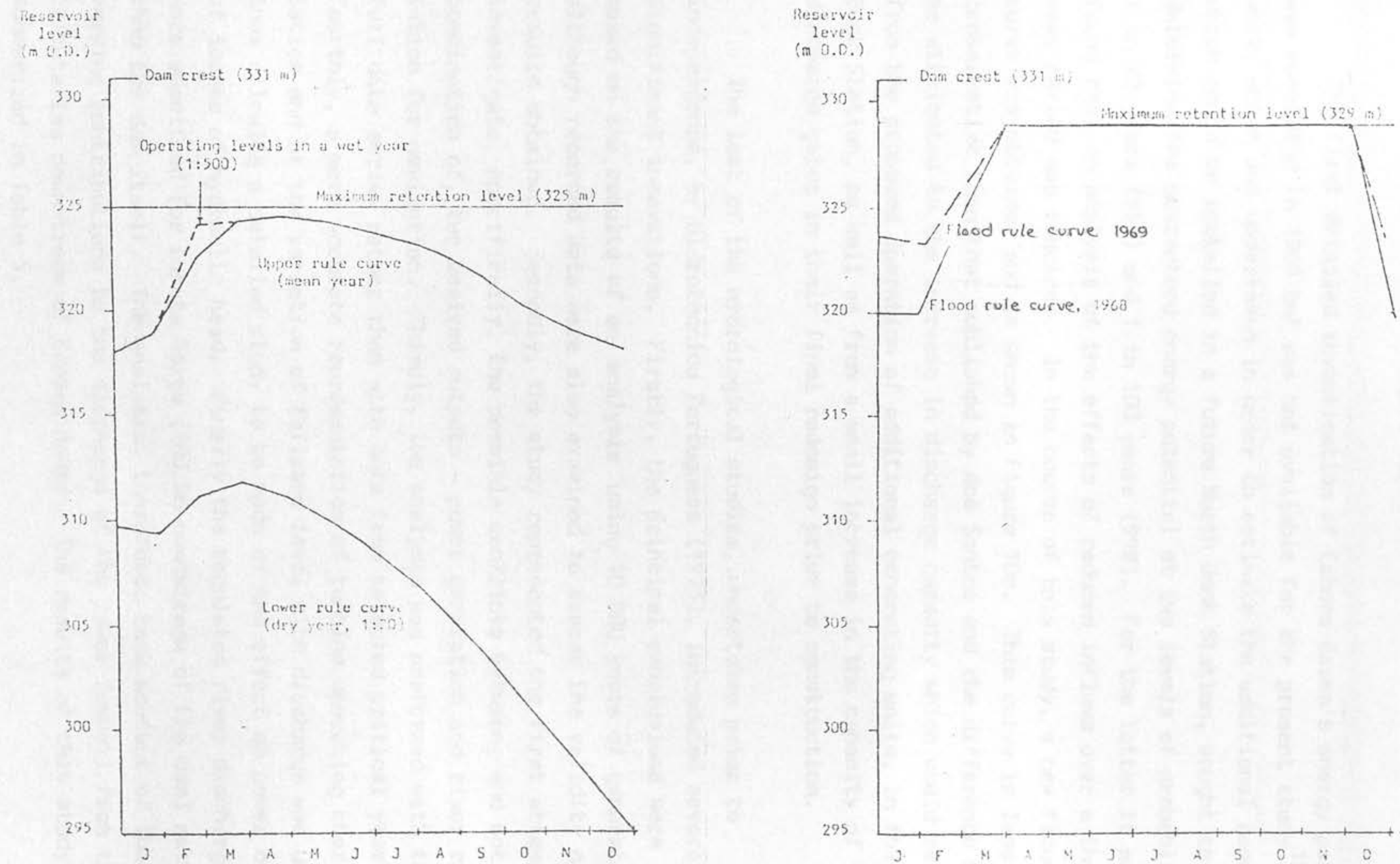
* The maximum flood discharge envisaged from the dam, 4 400 m^3/s, was a considerable underestimation.



(a) 1965 (Source, *Plano Geral*, 55.1, Fig. 10)

(b) 1968 (Source, dos Santos (1968)) and
1969 (Source, Hidrotécnica Portuguesa (1973))

Figure 10: Operating rule curves for Cabora Bassa proposed by Hidrótecnica Portuquesa.

in detail by dos Santos (1968) and the form of the new rule curve which was calculated is shown in Figure 10b.

The first detailed investigation of Cabora Bassa's energy potential was completed in 1969 but was not available for the present study[184]. This work, which was undertaken in order to estimate the additional capacity which could be installed in a future North Bank Station, sought to determine the guaranteed energy potential at two levels of probability - 1 in 20 years (95%) and 1 in 100 years (99%). For the latter it was found that an analysis of the effects of reduced inflows over a three year period was required. In the course of this study, a new flood rule curve was obtained and is shown in Figure 10b. This curve is less conservative than that published by dos Santos and the difference may be attributed to the increase in discharge capacity which would result from the proposed operation of additional generating units, in the North Bank Station, as well as from a small increase in the capacity of the discharge gates in their final redesign prior to construction.

The last of the hydrological studies, undertaken prior to independence, by Hidrotécnica Portuguesa (1973), introduced several significant innovations. Firstly, the principal conclusions were based on the results of an analysis using 10 000 years of generated data although recorded data were also examined to assess the validity of the results obtained. Secondly, the study represented the first attempt to investigate, specifically, the possible conflicts between, and optimal combination of, two desired outputs - power generation and river regulation for navigation. Thirdly, the analysis was performed with the full data series rather than with data from selected critical years. Fourthly, a more accurate representation of turbine operating characteristics and of the variation of tailrace level with discharge was used, thus allowing a detailed study to be made of the effect on power output of losses of hydraulic head. Finally the regulated river discharges were specified for Lupata Gorge (200 km downstream of the dam) rather than the dam itself. The analysis, therefore, took account of the varying contributions to the discharge of the lower Zambezi from the tributaries downstream of Cabora Bassa. The results of this study are summarized in Table 5.

Table 5: Summary of the results of the Cabora Bassa simulation undertaken by Hidrotécnica Portuguesa (1973)

(a) Simulation using 1 000 year data series (part of the 10 000 year series of generated data)

Target flow at Lupata (m^3/s)	Cabora Bassa Phase 1 (1600 MW) Mean annual energy deficit (GWh)	Cabora Bassa Phase 1 (1600 MW) Number of months of navigation flow deficit (%)	Cabora Bassa Phase 2 (2177 MW) Number of years of energy deficit	Cabora Bassa Phase 2 (2177 MW) Mean annual energy deficit (GWh)	Cabora Bassa Phase 2 (2177 MW) Number of months of navigation flow deficit (%)
1900	*	*	5	19	0.1
2000	*	*	7	21	0.2
2100	*	*	8	32	0.3
2200	*	*	24	100	1.1
2300	*	*	44	170	4.0
2400	10	0.5	100	350	6.3
2500	27	1.2	160	540	
2600	60	2.6			
2700	100	4.9			
2800	160	7.3			

(b) Simulation using recorded data for period 1931-71

Target flow at Lupata (m^3/s)	Cabora Bassa Phase 1 (1600 MW) Mean annual energy deficit (GWh)	Cabora Bassa Phase 1 (1600 MW) Number of months of navigation flow deficit (%)	Cabora Bassa Phase 2 (2177 MW) Number of years of energy deficit	Cabora Bassa Phase 2 (2177 MW) Mean annual energy deficit (GWh)	Cabora Bassa Phase 2 (2177 MW) Number of months of navigation flow deficit (%)
2300	*	*		300	3.0
2400	70	2.4		370	4.1
2500	100	3.7		420	4.7
2600	120	4.5			

* negligible or zero

Following independence, the first significant reassessment of the hydrology of the Cabora Bassa Project was undertaken, by consulting engineers Rendel, Palmer and Tritton (RPT), for the design of a flood warning system which had been proposed after the 1978 floods. RPT submitted three reports (1978, 1979 and 1980), the first was a short interim report containing a hydrological analysis which, because of poor data and certain invalid approximations, was totally superseded by the two subsequent reports.

The RPT (1979) report contained a study of alternative operating procedures, for Cabora Bassa, which would enable increased flood relief downstream to be achieved whilst meeting all existing commitments to power supply (principally, those specified in the agreement with Escom). The numerical analysis was based on a monthly water balance model for the reservoir similar to that used by Hidrotécnica Portuguesa (1973) and utilizing many of the same system parameters. However, the flood rule curve of dos Santos (1968) was adopted in preference to the 1969 curve. For their model RPT calculated a new set of input data, a forty-eight year series of monthly inflows, which was used to simulate the continuous operation of the project. An energy rule curve was derived, see Figure 11a, which would guarantee the firm power output required over the full period of the simulation. The purpose of the curve was different from that proposed in the *Plano Geral*. Rather than indicating the reservoir levels below which power output (or regulated discharges) would have to be reduced, RPT's curve indicated the reservoir levels above which additional discharges from the dam could be made without jeopardizing future power production. In the *Plano Geral* analysis it had been assumed that no additional discharges would be made until the level of the flood rule curve was reached, after which the gates would be fully opened, whereas RPT proposed that, for reservoir levels above the energy rule curve, discharges should be made up to a chosen 'threshold' in order to reduce the need for higher discharges at a later date. The threshold was to be chosen as the maximum discharge which could be made without causing serious flooding downstream. Three further refinements were included in the RPT (1979) study. Firstly, a detailed simulation of the operation of the Kariba Project was made in order to improve the quality of the input data for the Cabora Bassa simulation and to investigate the effect of operating policies at Kariba on the output

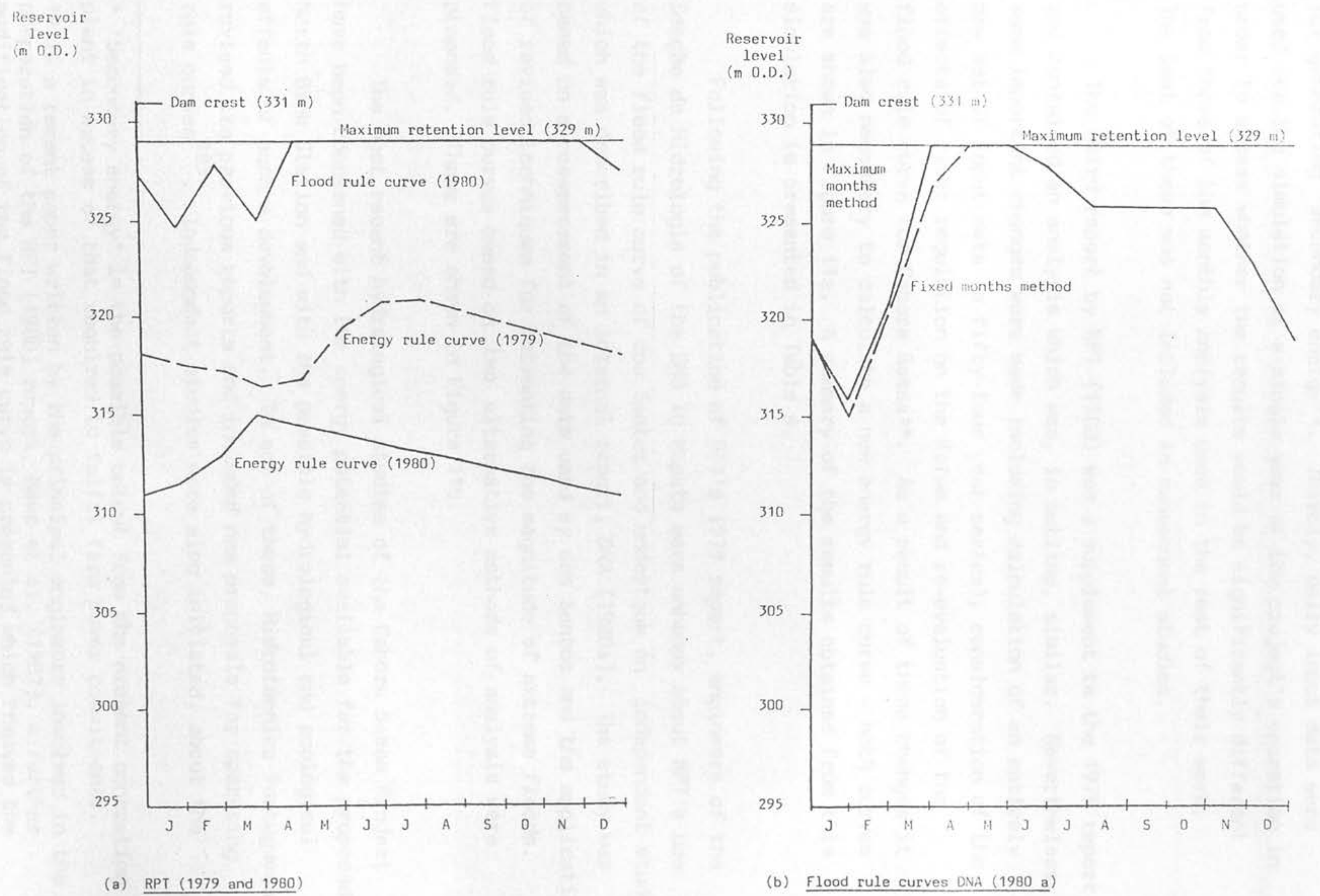


Figure 11: Operating rule curves for Cabora Bassa proposed by RPT and DNA.

from Cabora Bassa. Secondly, an analysis was made of the potential for generating 'secondary energy'*. Thirdly, daily input data were used for the simulation of a single year of the project's operation in order to assess whether the results would be significantly different from those of the monthly analysis used in the rest of their work. The last of these was not included in subsequent studies.

The third report by RPT (1980) was a supplement to the 1979 report and contained an analysis which was, in outline, similar. Nevertheless, some important changes were made including calculation of an entirely new set of input data (a fifty-four year series), consideration of the effects of river regulation on the Kafue and re-evaluation of the flood rule curve for Cabora Bassa**. As a result of these changes it was also necessary to calculate a new energy rule curve - both curves are shown in Figure 11a. A summary of the results obtained from this simulation is presented in Table 6.

Following the publication of RPT's 1979 report, engineers of the Secção de Hidrologia of the DNA in Maputo were unhappy about RPT's use of the flood rule curve of dos Santos and undertook an independent study which was described in an internal report, DNA (1980a). The study was based on a reassessment of the data used by dos Santos and the application of revised techniques for estimating the magnitude of extreme floods. Flood rule curves based on two alternative methods of analysis were proposed. These are shown in Figure 11b.

The most recent hydrological studies of the Cabora Bassa Project have been concerned with the energy potential available for the proposed North Bank Station and with the possible hydrological and ecological effects of such a development. In one of these, Hidrotécnica Portuguesa revised its previous reports and included new proposals for operating rule curves[185]. Independent studies were also initiated, about the

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* 'Secondary energy' is the possible output from the present generating plant in excess of that required to fulfil firm power commitments.

** In a recent paper written by the principal engineers involved in the preparation of the RPT (1980) report, Haws et al. (1982), a further modification of the flood rule curve is presented which removed the anomalously high level previously suggested for 1 March, see Figure 11a.

Table 6: Summary of the results of the Cabora Bassa simulation undertaken by RPT (1980)

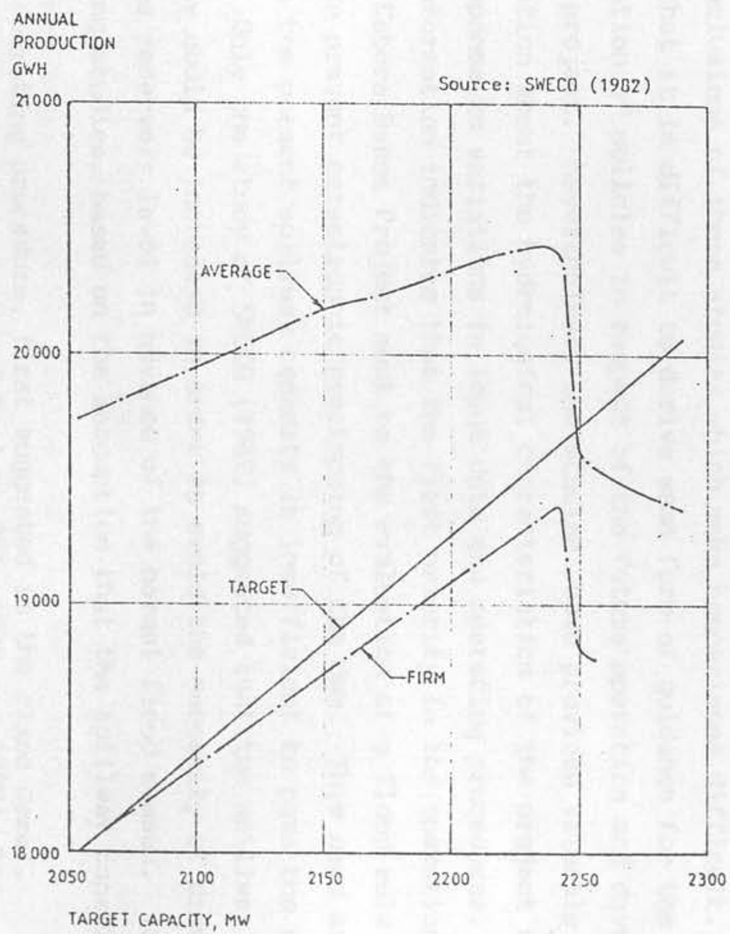
Selected 'threshold' discharge (m^3/s)	Assumed operating policy at Kariba (load factor)	Average secondary energy available (TWh/yr)	Peak monthly flood release (m^3/s)	Threshold exceeded during 54-year simulation (number of years)
7 000	0.6	1.59	9 560	1
8 000	0.6	1.57	8 660	1
6 000	0.6	1.64	10 460	2
-*	0.6	1.61	14 410	27
7 000	0.8	1.74	7 910	1
8 000	0.8	1.72	8 000	0

(In each of the simulations, the assumed firm energy commitment of 14.07 TWh/yr was fulfilled)

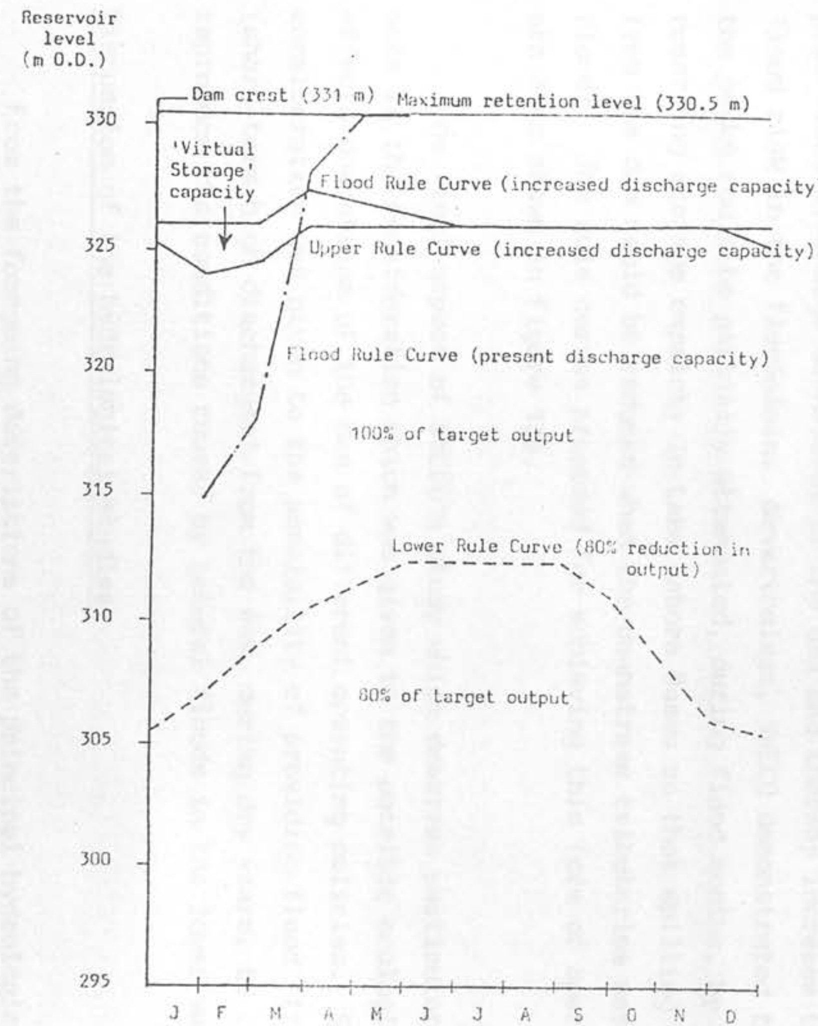
* This case was selected to simulate the operation of the project for maximum security of power output, that is, with the energy rule curve coincident with the flood rule curve. There was no 'threshold' as such but the number of years in which discharges exceeded 7 000 m^3/s was recorded.

same time, by the Swedish consulting engineers, SWECO, as part of the pre-investment programme of investigations for the North Bank Project commissioned by Electricidade de Moçambique. The report on hydrology and water management, SWECO (1982), provides some new and interesting results and conclusions. The method of analysis was based on a monthly water balance model, similar to that used in previous studies, with the input data once more reassessed and certain system parameters modified. One of the principal purposes of this study was to investigate the hydrological implications of attempting to attain various levels of continuous power output from additional installed capacity in the North Bank. The results, which present reliability of output and availability of secondary energy as functions of the target level of power production, are shown graphically in Figure 12a. The dramatic decrease in these outputs in SWECO's simulation, once the target output exceeds a certain value, results from loss of hydraulic head and consequent loss of turbine efficiency as the reservoir approaches its minimum operating level. In order to avoid a sudden loss of that output SWECO proposed that the adopted energy rule curve should be similar to that of the lower rule curve in the *Plano Geral* so that when the reservoir level falls below the rule curve the power output would be reduced by a given percentage. The extent of this reduction would be such that, with the data used in the simulation, no further loss of output would occur. If it were decided that only a small percentage reduction in output could be tolerated the corresponding rule curve would have higher levels, and reductions in output would occur more frequently than if a higher percentage reduction were permissible. Four alternative rule curves were produced by SWECO for energy reductions ranging from 12% to 30%. The rule curve for a 20% reduction in output is shown in Figure 12b.

A further part of the SWECO study was a re-evaluation of the flood rule curve. An initial curve, shown in Figure 12b, was similar in form to that of DNA (1980a). SWECO suggested, however, that if the maximum discharge capacity of the dam were to be increased by about 25% (3 600 m^3/s), by the construction of an additional spillway, it would be possible to replace the flood rule curve by a single normal maximum operating level for the reservoir. The change, which would provide undoubted benefits as regards power generation, would, increase the



(a) Results of energy studies for Cabora Bassa



(b) Operating rule curves, SWECO (1982)

Figure 12: The results of energy studies by SWECO and the rule curves proposed.

peak flood discharge downstream of the dam and thereby increase the flood risk in the floodplain. Nevertheless, SWECO demonstrated that the peaks could be partially attenuated, during flood months, by reserving storage capaicty in Lake Cabora Bassa so that spilling from the dam could be reduced when the downstream tributaries were in flood*. The rule curves proposed for achieving this form of operation are also shown in Figure 12b.

One final aspect of SWECO's study which deserves particular note is the consideration which was given to the possible ecological effects downstream of the dam of different operating policies. Special consideration was given to the possibility of providing flood 'freshets' (short-term high discharges) from the dam, during dry years, to reproduce the conditions caused by natural floods in the lower valley.

Discussion of the hydrological studies

From the foregoing descriptions of the principal hydrological studies which have been undertaken for Cabora Bassa, it is readily apparent that there are significant differences both in the methodology and conclusions of these studies which make comparisons difficult. This means that it is difficult to derive some form of guidance for the formulation of policies in respect of the future operation and development of the project. Nevertheless, the studies have provided valuable information about the hydrological characteristics of the project and its response to variations in input data and operating procedures. Such information indicates that the first priority in the operation of the Cabora Bassa Project must be the evaluation of a flood rule curve to prevent catastrophic overtopping of the dam. This need arises because the present spillway capacity is insufficient to pass the design flood. Only the study of SWECO (1982) suggested that the spillway capacity could be increased in order to avoid the necessity of drawing down the reservoir level in advance of the normal flood season. The remaining studies, based on the assumption that the spillway capacity

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* This operating procedure, first suggested in the *Plano Geral, 55.1*, p7 and examined in some detail by RPT (1979 and 1980), has been termed the 'virtual storage' of tributary flows.

will remain unchanged, used a variety of methods to calculate the flood rule curve, and derived results which vary considerably. In the light of the need to adopt the most suitable flood rule curve, a thorough investigation of the origins of these differences and their implications for the operation of the project is included later in the present chapter.

Having determined a suitable flood rule curve, the majority of studies proceeded by simulating the operation of Cabora Bassa as a single purpose project either for power generation or, prior to 1969, for river regulation to provide navigation downstream. Operated in this manner, the principal hydrological constraint is the extent to which the discharges may be regulated, by long-term storage, so as to maintain output over a long period of below-average inflows. With the present installed capacity there is little likelihood that power output from the Cabora Bassa Project will be curtailed due to a shortage of water unless the form of the flood rule curve finally adopted requires an annual drawdown greater than that in any of the studies considered above. On the other hand, if, as it appears at present, construction of the North Bank Station is under serious consideration a study of the most critical sequence of inflows is requred to determine the maximum power production which could be sustained*. Again, the studies which address this problem differ considerably in their conclusions. This question is also examined in greater detail later in the chapter.

A limited number of the studies considered the implications of attempting to operate Cabora Bassa as a multiple purpose project; this is another subject which is given more detailed treatment later in the chapter. The study by Hidrotécnica Portuguesa (1973) is of particular interest because it demonstrates that even with the two more-or-less compatible outputs, of hydroelectric power and river regulation downstream, any policy which seeks to maximize either output leads to reduced levels of the other, see Table 5.

A potential conflict clearly exists between procedures designed to maximize the level of guaranteed power output from Cabora Bassa and those designed to provide maximum flood alleviation downstream. The

* This assumes that Cabora Bassa will contune to provide mainly base-load power.

conflict is not, however, readily apparent in the results of the RPT studies of flood alleviation because a single level of power output was used for most of the simulations*. In fact, with the present level of power output, RPT demonstrated that appreciable flood alleviation could be achieved by adopting the proposed policy of 'threshold' discharges described above. This conclusion is undoubtedly important for the operation of the project as it stands.

SWECO also investigated another possible objective in the operation of the Cabora Bassa Project - the preservation of an annual peak in the discharge hydrograph of the lower river during the natural flood season. The floodplain inundation which this would cause would, it has been suggested, be environmentally and agriculturally beneficial. Again, reservoir simulation analysis indicated that the objective could only be achieved at the cost of power output.

The input data used in the hydrological studies of Cabora Bassa described above show considerable variation and have given rise to significant differences between the results of the several simulations. There are relatively few long-term records of river discharge available for the Zambezi and although a wide variety of techniques of data analysis, synthesis and correlation have been used, in an attempt to improve the quality of the inflow data, none has been entirely satisfactory. In addition, the studies have all been undertaken on the assumption that the rainfall and runoff characteristics of the catchment have long-term stability, an assumption which does not appear to be consistent with a number of the hydrological records available. A detailed discussion of the factors which might affect the quality of input data used in the analysis of the Cabora Bassa Project forms a separate study which is included in Appendix 6. This appendix contains an examination of the possibility that changes have occurred in hydrological characteristics of the basin during the fifty-year period for which records exist and includes comparisons between rainfall records and discharge records for three important catchments. A more detailed application of the techniques of runoff estimation using meteorological data and information about

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* RPT (1979) Table 4.3 includes the results of a simulation for 'enhanced energy production' (energy output increased by 4%) which resulted in a significant increase in flood discharges.

catchment characteristics would, however, be very difficult to achieve for Cabora Bassa's catchment in view of its size and the inadequate meteorological data and catchment information currently available.

For the Cabora Bassa Project the analysis of recorded data is of particular importance because the operating procedures for the project have been heavily dependent on the rule curves so obtained. The operators of Cabora Bassa have direct access to very little current hydrological information about the reservoir catchment apart from information about the discharges from the Kariba Dam. In the past, poor communication between HCB and CAPC has, at times, deprived HCB of this vital information. Thus, information which might have allowed a more flexible application of the chosen rule curves, by providing an indication of impending low or high inflows, possibly a month or more in advance, has not been available.

The operators of the Kariba Project have been better served in this respect having at an early stage, established a network of telemetered river gauges with the first three, located in north-west Zambia, entering operation in 1963. Nevertheless, they continued to use other hydrological and meteorological data from Zambia and Angola. By 1976, the supply of this data had virtually ceased not only from Angola but also from stations in Zambia many of which the government was no longer willing to finance. The CAPC was compelled, therefore, to accept financial responsibility for the operation of a number of key hydrological stations in Zambia and also to introduce a number of telemetered rainfall stations although these, at first, proved unreliable[186].

Direct participation in the collection of data, in this way, is not possible for the Cabora Bassa Project. No more than 3% of Cabora Bassa's catchment area lies in Mozambique whereas the approximate proportions within Zambia, Zimbabwe and Angola are 60%, 20% and 15% respectively. Thus, Mozambique, by itself, can do little to improve the hydrological network for the benefit of those operating Cabora Bassa; telemetered rainfall stations located solely within Mozambique would be of little value in predicting the total runoff of the catchment whilst telemetered river gauges would provide, at most, a few hours' warning of large inflows to the reservoir. On the other hand, over 60% of Cabora Bassa's catchment area is regulated by the Kariba Project and approximately 15% by the Kafue Project the remainder being made up of largely unregulated tributaries distributed, as approximate proportions of the total catchment, as follows: Zambia, 16% (comprising mainly the Luangwa basin); Zimbabwe, 4%; and, Mozambique, 3%[187]. A knowledge of discharges from the Kariba and Kafue projects together with telemetered levels from, perhaps, two gauges on the Luanqwa would allow fairly reliable estimates of inflow to be made three or four days in advance. More detailed information about projected discharges from Kariba and Kafue, based on hydrological data from their own catchments, would enable the engineers at Cabora Bassa to obtain an approximate indication of expected inflows as much as a month in advance.

An exchange of data, such as that proposed above, has not previously occurred although the operators of the Kariba Project undertook, initially, to supply the authorities in Mozambique with warnings of impending changes in the rate of discharge from the dam up to two weeks in advance. Throughout the 1960s it was the normal practice for the CAPC to send such warnings, together with calculations of the date and magnitude of the expected changes in river level at various points downstream, to various agencies including the Governor General of Mozambique, the headquarters of the MFPZ and the Sena Sugar Estates[188]. During the construction of the Cabora Bassa Dam, the CAPC's engineers modified their regular operating procedures to suit the construction schedule and, prior to that, the CAPC appears to have responded to appeals from the Sena Sugar Estates about excessively high or low flows. After Mozambique's independence warnings were not issued so prolifically, although the CAPC continued to advise the HCB headquarters in Lisbon of intended discharge gate operation at Kariba. Thus, even during the disasterous flood of 1978, two weeks' warning of flood discharges was given[189]. Thereafter, HCB approached the CAPC for a comprehensive reappraisal of recorded data and for a weekly supply of current hydrological data form Kariba[190].

The hydroelectric projects at both Kariba and Kafue are of considerable importance not only in the supply of hydrological information to Cabora Bassa but also in their capacity to regulate the inflows to Lake Cabora Bassa. The effects of such regulation on the flood rule curve at Cabora Bassa and the energy potential of the project are considered below, but the extent of the effect should not be overestimated. For example, it has been suggested that during the most critical period of the 1978 flood only 40% of Cabora Bassa's inflow originated from Kariba[191]. Nevertheless, RPT (1980) concluded that:

> The influence of the Kariba operating policy on Cabora Bassa is dominant. (p3)

It was for this reason that RPT's (1980) report included:

> the major new recommendation ... that communication between the authorities responsible for controlling the water resources on the Zambezi must be improved. (p9)

According to RPT, communications should include not only the exchange of information relevant to the day-to-day operation of Cabora Bassa but also discussion of the operating policy and design of planned future projects.

Before concluding this general introduction to the hydrology of the Cabora Bassa Project it is necessary that reference should be made to the current operating porcedures being adopted by HCB. In fact, it is extremely difficult to discover what these policies might be either by approaching HCB directly, or by studying records of the reservoir's operation. RPT (1979) assumed that HCB had adopted the flood rule curve of dos Santos (1968) which has been derived for the operation of the project without a North Bank Station. Furthermore, RPT assumed that, in order to provide maximum security of power output, HCB was using an energy rule curve which was co-incident with this flood rule curve. If RPT were correct about HCB's use of the 1968 flood rule curve, reservoir operating records indicate that it has not been rigidly adhered to. In two of the six flood seasons from December 1974 to December 1980 the levels of the reservoir were allowed to exceed those specified by dos Santos, on one occasion by over 3 m[192]. In the same period the reservoir level reached 326.0 m in three of the years an event which, dos Santos had suggested, would occur extremely rarely (probability considerably less than 1 in 100 years).

The explanation of their operating procedures given to the writer by HCB staff in Songo was less than satisfactory; it appeared as if new rule curves were drawn each year by the hydrologists in Lisbon. The rule curves in use in 1979 are reproduced in Figure 13 but no explanation of their method of application is available. The upper rule curve appears to be a flood rule curve yet, until 1 May, its levels are appreciably below those of dos Santos' curve. Furthermore, the target drawdown level for 1 January, 1979, was 314.0 m (a considerable discharge of water was made towards the end of 1978 to achieve this target) whereas the target level for 1 January, 1980, was the dos Santos level of 320.0 m. Such variations are not fully consistent with the normal understanding of flood rule curve operation.

Description of the numerical model adopted

In order to investigate more closely certain hydrological characteristics of the Cabora Bassa Project further analysis of the system was undertaken. The numerical model adopted was based on the water balance simulations previously undertaken and of which the principal details are described below.

Time intervals of one month were adopted for the analysis, the input data being based on the fifty-four year series used in RPT (1980) which gives monthly inflows to Cabora Bassa derived from existing records. The initial studies by Hidrotécnica Portuguesa had placed the primary emphasis on annual, rather than monthly, discharge data, with monthly discharges being derived from these by applying distribution coefficients. Although the assumption of a constant pattern of seasonal distribution, on which this method was based, is unrealistic it facilitated the use of a long series of generated (synthetic) annual discharge data in a later study which, in turn, facilitated a more precise* evaluation of the reliability of selected outputs. Another variation adopted by Hidrotécnica Portuguesa in the study reported by dos Santos was the incorporation of appropriate time-lags, in the evaluation of monthly discharges from records from different locations, to allow

* It was not, necessarily, more accurate since the accuracy of the results depends on the assumptions on which the data generation model was based.

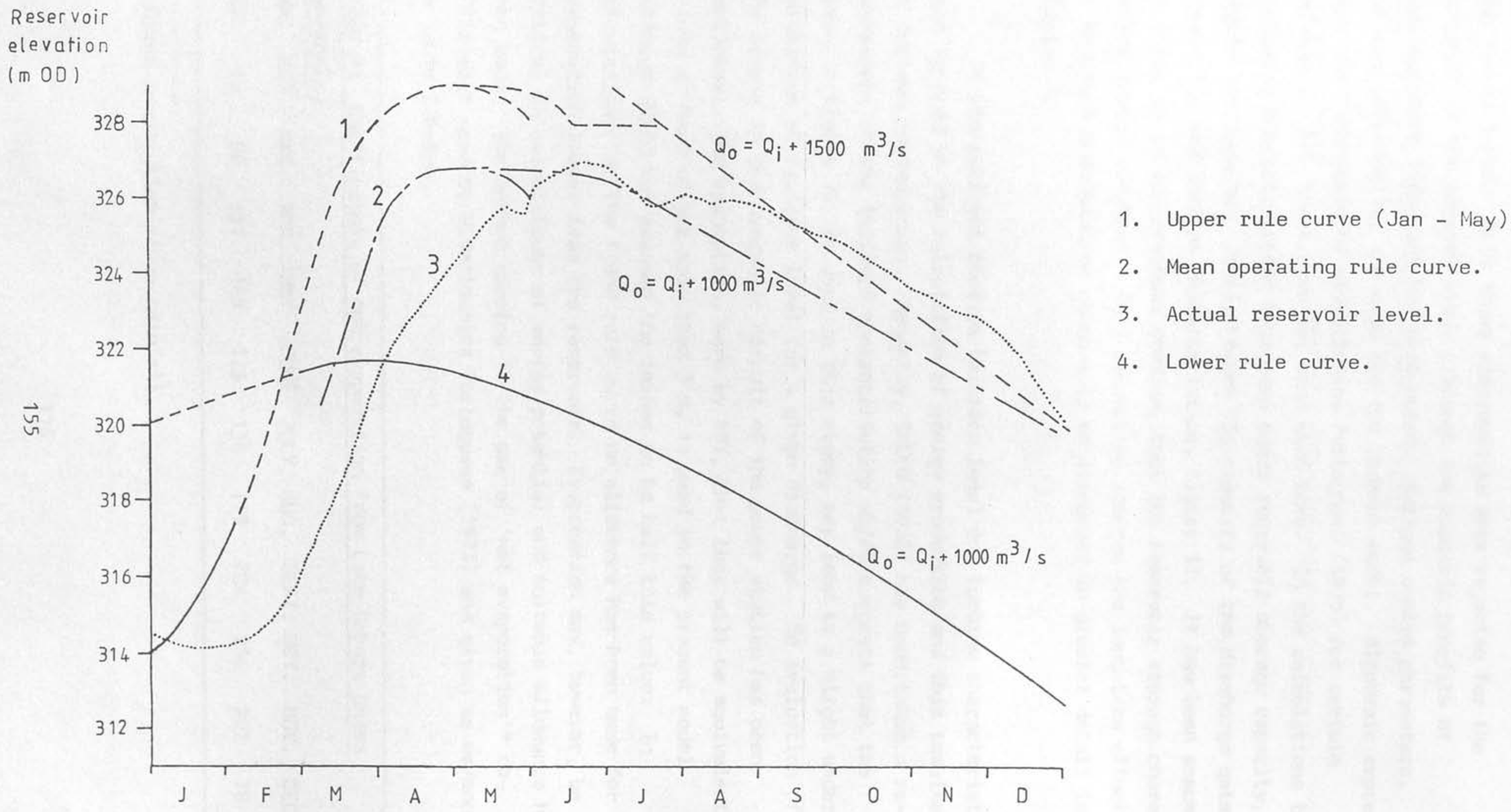


Figure 13: Operating rule curves used by HCB during 1979

for travel times. Both these alternatives were rejected for the purposes of the present study although the possible benefits of incorporating time-lags has been noted. Various system parameters, defined graphically, are used for the present model. Algebraic expressions were also developed by Hidrotécnica Portuguesa (1973) for certain relations, but these have not been used here. In the calculations the following characteristics have been used: reservoir storage capacity, Figure 14; tailrace level, Figure 15; capacity of the discharge gates, Figure 16; and turbine characteristics, Figure 17. It has been assumed in this, as in all previous studies, that the reservoir storage characteristics remain constant. This assumption ignores the long-term effect of sediment accumulation which will be discussed in greater detail in Chapter 5.

In the earliest studies tailrace level and turbine characteristics were ignored in the calculation of energy production and this resulted in serious inaccuracies. Recently, SWECO (1982) has undertaken a re-assessment of the tailrace characteristics which suggests that the curve in Figure 15, as used in this study, may lead to a slight under-estimation of tailrace level for a given discharge. No evaluation of the losses in the hydraulic circuit of the power station has been published. The assumption, made by RPT, that they will be equivalent to a loss of head of not more than 3 m, is used in the present model although SWECO has assumed the losses to be half this value. In calculations for the flood rule curve no allowance has been made for evaporation losses from the reservoir. Evaporation may, however, be critical in calculations of energy potential and suitable allowance has been made. The method adopted is the use of 'net evaporation'* coefficients used by Hidrotécnica Portuguesa (1973) and given as mm/month in Table 7 below.

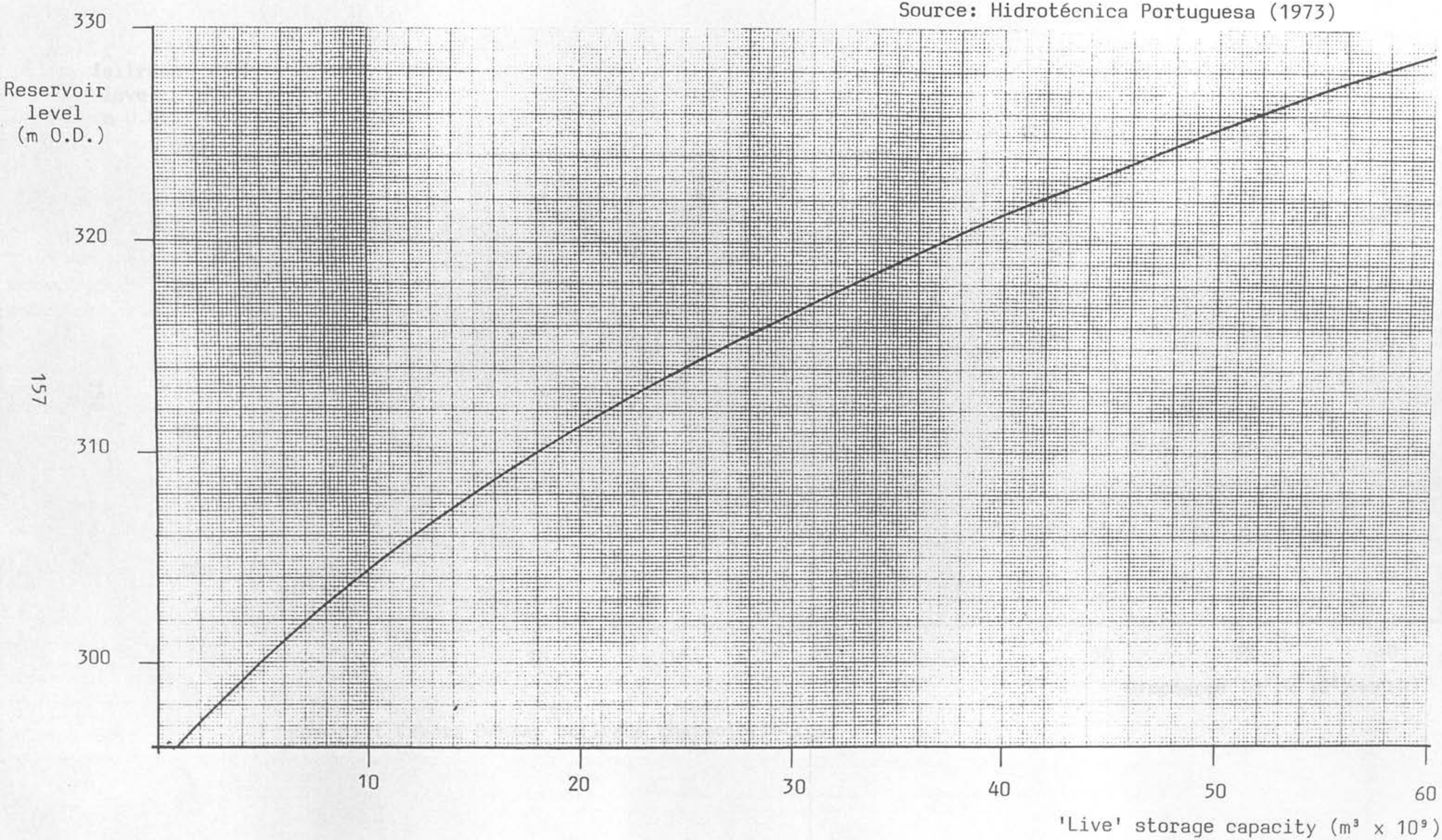
Table 7: Coefficients of net evaporation from Lake Cabora Bassa (mm/month)

JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
17	19	98	157	149	123	134	179	206	256	202	78

* Gross evaporation minus rainfall.

Figure 14: Cabora Bassa, reservoir storage characteristics

Source: Hidrotécnica Portuguesa (1973)



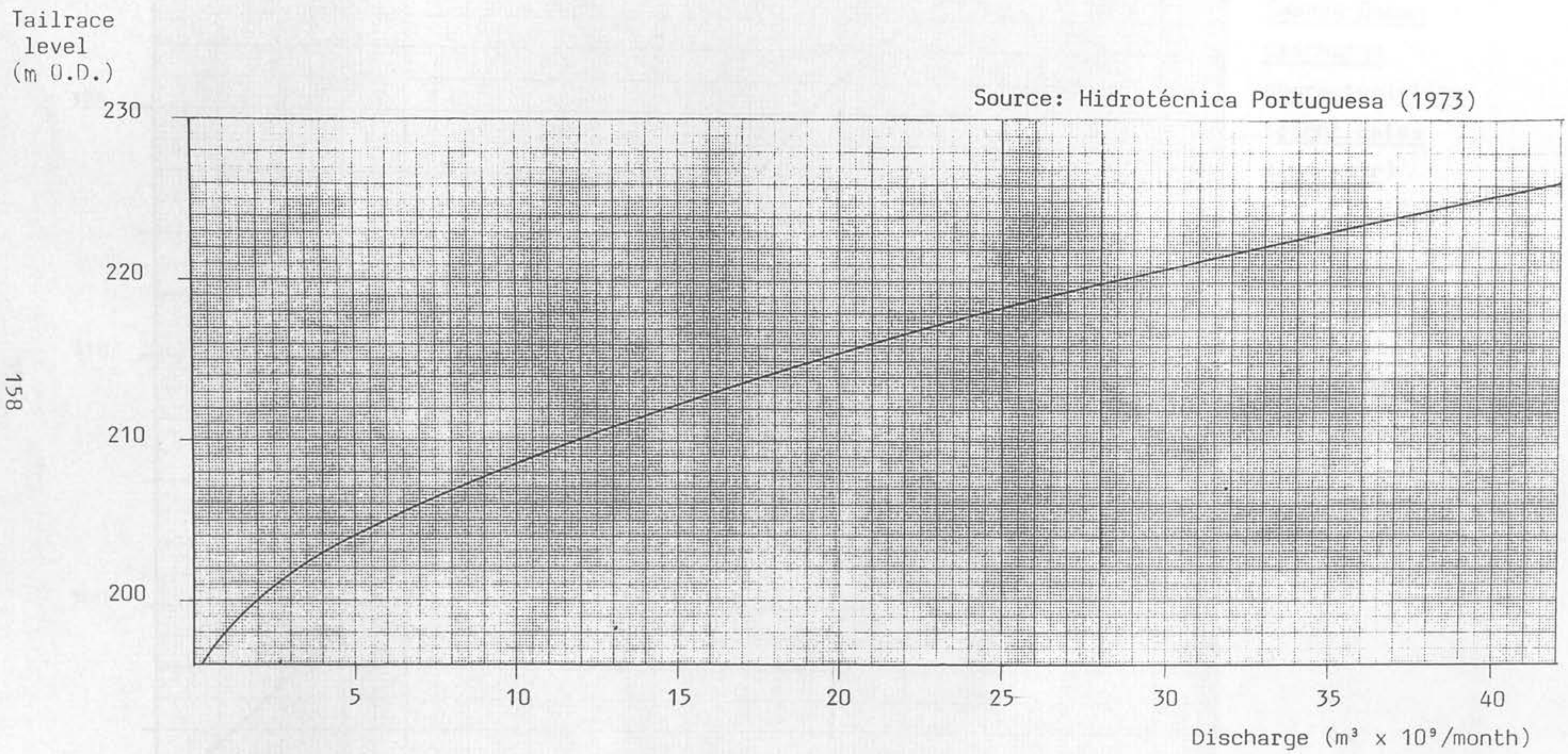


Figure 15: Cabora Bassa, tailrace characteristics

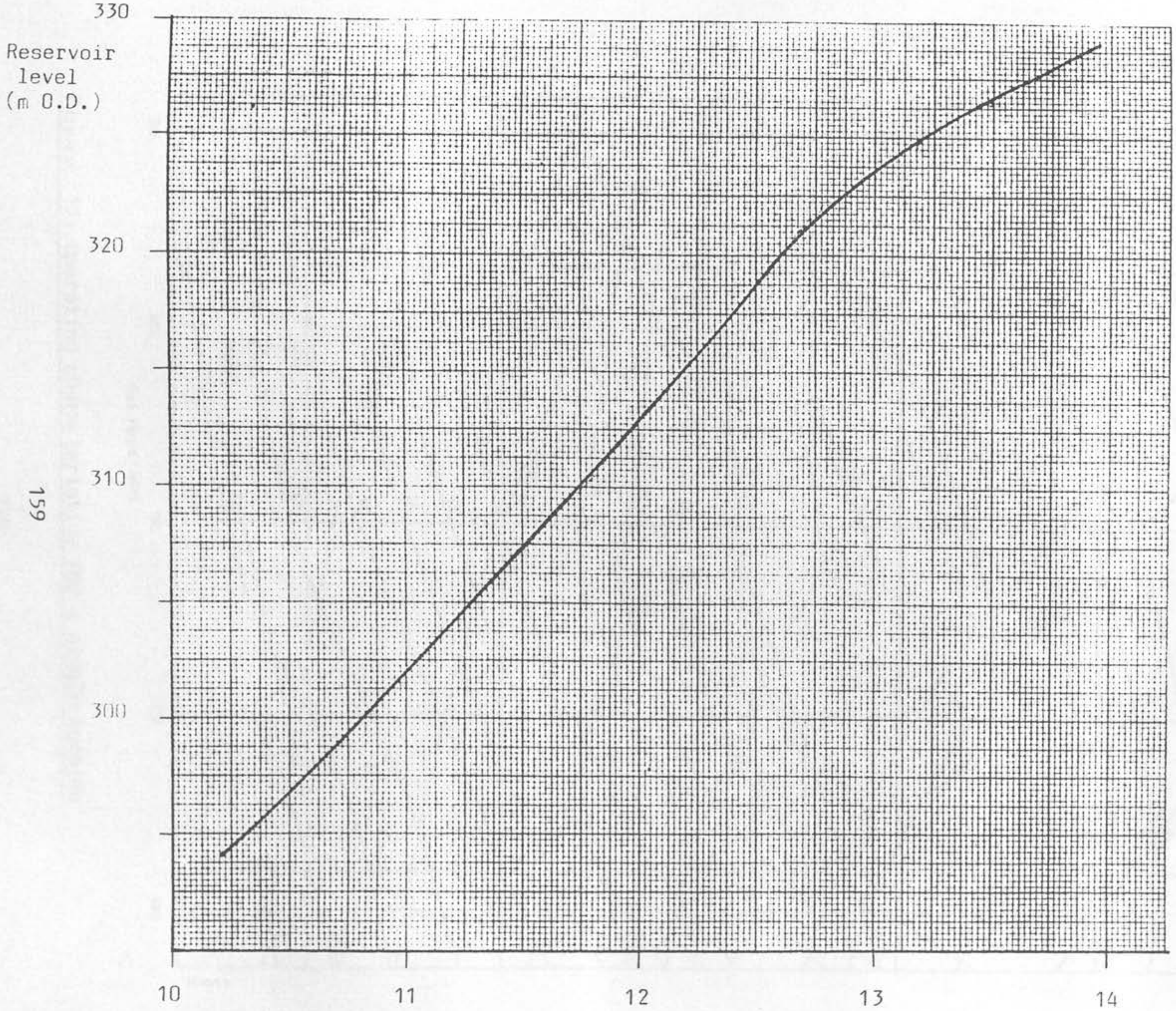


Figure 16:

Cabora Bassa discharge characteristics (eight gates plus weir)

Source:

Hidrotécnica Portuguesa (1973)

Source: RPT (1979)

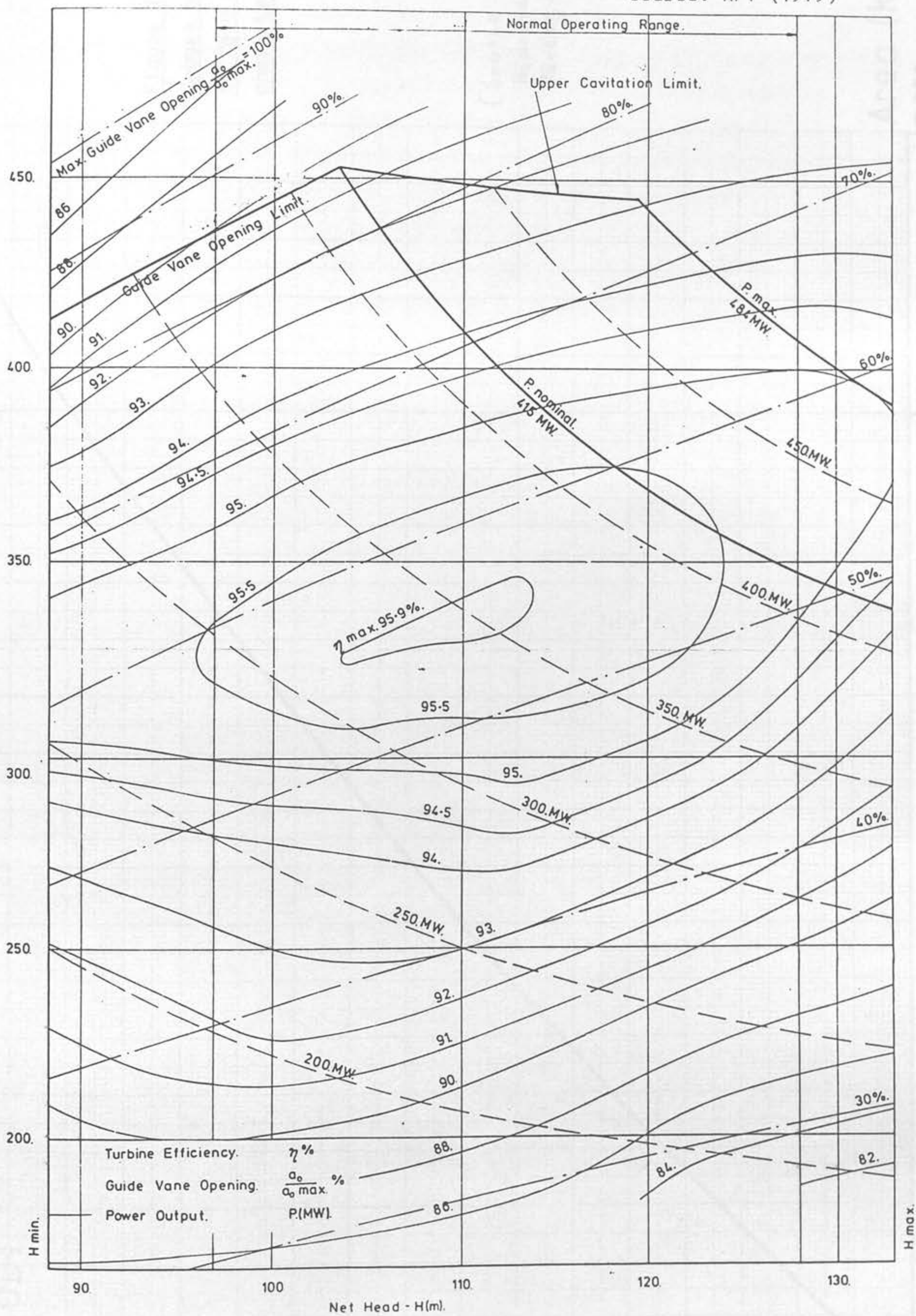


Figure 17: Operating characteristics for a single turbine

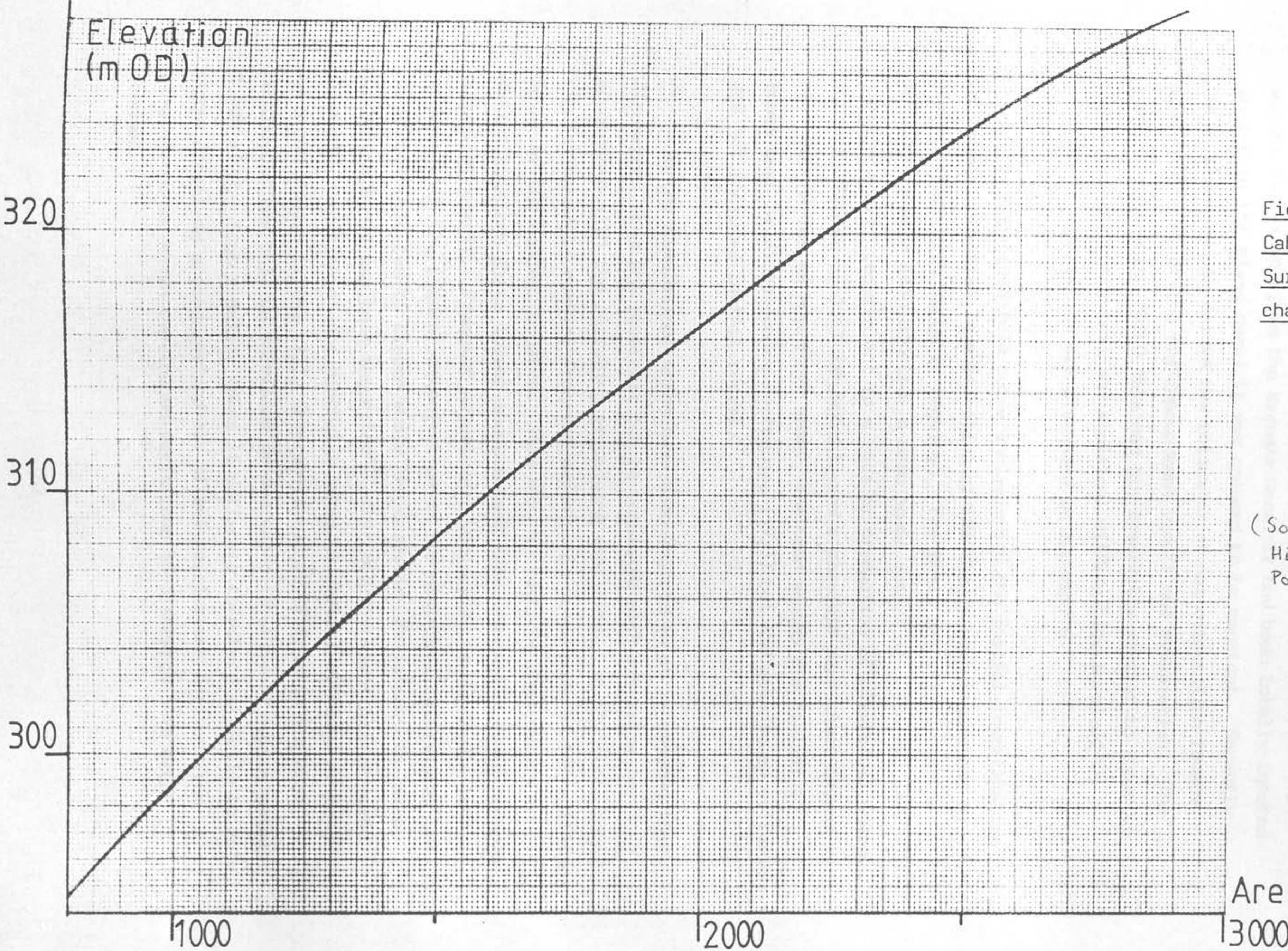


Figure 18:
Cabora Bassa
Surface area
characteristics.

(Source:
Hidrotécnic
Portuguesa)

In order to apply them in the simulation, the surface area characteristics of the reservoir must also be known, see Figure 18. Earlier studies had adopted various approaches to the calculation of evaporation; for example, in the *Esquema Geral* it had been totally ignored whilst in the *Plano Geral* it was assumed to be constant. Recently SWECO attempted to derive new estimates of net evaporation losses taking account of the pre-impoundment runoff and evaporation. The coefficients which SWECO obtained are remarkably similar to those of Table 7. The conceptual and empirical difficulties involved in estimating evaporation are discussed in Appendix 6.

For the flood rule curve analysis and the initial investigation of energy potential, specification of the energy output demanded by the contract with Escom is required. For this, the values used by RPT (1979) have been adopted: a mean power output of 1 605 MW, at turbine shaft, (equivalent to a rate of production of electrical energy of 14.07 TWh/yr or 1.17 TWh/month), and a possible peak power demand of 1 960 MW for 46 hours per week. The mean values are similar to those used by Hidrotécnica Portuguesa (1973) but the peak power criterion was not included in that report.

In the simulations which have been undertaken it is assumed that discharges from the reservoir can be regulated with precision in accordance with the operating procedures specified. In practice, such regulation would require frequent adjustments to be made to the spilling level of the discharge gates. This may, in fact, be unnecessary in most situations since larger changes made less frequently would produce a similar result. Frequent adjustments would also be difficult to achieve with the present organization of HCB where all information has to be communicated to Lisbon where the operating decisions are taken. Furthermore, it has been suggested[193] that HCB's current policy seeks to avoid operation of the discharge gates at partial openings so as to avoid damage to the sills from cavitation. If this is the case, discharges can only be increased or decreased in units of approximately 1 500 m^3/s. Such a policy makes it difficult to adhere strictly to rule curve operating procedures and may affect conclusions derived from simulations in which continuous variations in dishcarge have been assumed.

The flood rule curve

The concept of a flood rule curve and its application in the operation of the Cabora Bassa Dam have been mentioned earlier. Various alternative curves which have been proposed for Cabora Bassa are shown in Figures 10-13. Strictly speaking it is only necessary to define a flood rule curve for the critical months of, say, January to May but in practice the curves are extended to cover the whole year in order to achieve a gradual and controlled drawdown to the level required at the start of the critical period. Except in the study by SWECO (1982) it has always been assumed that the discharge capacity of the dam cannot be increased. Undoubtedly, it would be difficult to provide extra discharge gates now that the dam is in operation, particularly in view of the narrowness of Cabora Bassa Gorge. Nevertheless, the SWECO study showed the considerable benefit which could be achieved through relaxation of the flood rule curve conditions were it feasible to increase the maximum discharge capacity of the dam by 25%. On this basis the original designers of the dam might be criticized for not having provided the necessary discharge capacity. The original design has, however, been defended by Quintela et al. (1979) both on economic grounds and because increased discharge capacity would increase the problem of dissipating the energy of the spill water and preventing serious erosion in the narrow gorge downstream. Increased capacity would also increase the potential flood hazard in the lower Zambezi valley through the increased river flows which would occur.

Some of the important questions which remain unresolved in the evaluation of the flood rule curve for the Cabora Bassa Project must now be examined as numerical analysis indicates some sensitivity of the flood rule curve to possible amendments arising from consideration of these factors.

a) The effects of overtopping: The majority of previous studies failed to discuss possible overtopping of the Cabora Bassa Dam. It is not clear, therefore, whether the various writers considered limited overtopping to be admissible should their flood rule curve have proved to be inadequate for the control of design flood inflows. It is likely that most did not, but SWECO (1982) suggested that overtopping:

> might not be as catastrophic as if it had been an embankment dam. (p23)

For any dam, the most serious consequence of overtopping would be the possibility of its destruction resulting in almost total loss of the investment and releasing an extremely destructive flood wave*. In the case of an earth dam, overtopping of the unprotected embankment would result in its rapid erosion and virtually inevitable distruction. With a concrete arch dam, such as Cabora Bassa, immediate failure is less likely to occur but prolonged periods of overtopping might result in its failure particularly if the spilling water, falling directly to the foot of the dam, causes sufficient erosion to endanger the stability of the dam's foundations.

Even if failure of the dam does not occur, overtopping could result in unacceptable levels of damage either from the extra downstream flooding, which would result from exceeding the maximum discharge capacity of the dam, or from damage to the electrical installations. Should the North Bank Station be built overtopping would also cut off the only means of access to it - across the crest of the dam.

For these reasons, in the absence of a more detailed study of the possible effects, it will be assumed that overtopping of the Cabora Bassa Dam should be regarded as unacceptable in the evaluation of the flood rule curve.

b) Method of analysis of design flood data: The UK *Flood Studies Report*, referred to earlier, recommends the use of values of probable maximum flood obtained from estimates of extreme precipitation in the study of flood routing effects. In Britain, where few dams have catchments

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* Evidence from other dam failures quoted by Kirkpatrick (1977) suggests that complete failure of a dam the size of Cabora Bassa would result in a peak flood discharge of the order of 150 x 10^3 m^3/s - a factor of ten greater than the present maximum discharge capacity of the dam.

greater than 100 km^2, this approach offers distinct advantages. For basins larger than 500 km^2, however, Sutcliffe (1975) has warned that the technique 'should be used with care'. Despite the fact that Moraes et al. (1979) have used this approach in designing the spillway of the Itaipu Dam (between Brasil and Paraguay) which has a catchment area of 8.2×10^5 km^2, only slightly less than that of the Cabora Bassa Dam, 9×10^5 km^2, the techniques cannot be considered to have proven suitability for the present study. The study of extreme floods at Cabora Bassa must, therefore, be made by means of frequency analysis of existing river discharge records.

Unfortunately, in the past, frequency analysis of flood discharges has been undertaken, almost exclusively in relatively small catchments where discharges of short duration (less than a day) are the most critical in their flood impact. For Cabora Bassa, by contrast, because of the large catchment and the storage and discharge characteristics of the dam, the duration of the most critical flood inflows has been found to be of the order of three months. In previous studies of the Cabora Bassa Project the unsubstantiated assumption has been made that statistical techniques developed for short duration floods are equally applicable to floods of such long duration[194]. It has been necessary to accept this assumption for the present analysis, in the absence of further evidence, but it must be recognized that the suitability of techniques developed for the analysis of short duration floods to those of longer duration requires closer investigation.

The statistical study of floods depends on the assumption that flood frequency at a given location is defined by a unique relationship expressed, most commonly, in the form:

$$x = f(y)$$

Where x is a hydrological or meteorological parameter which measures flood intensity (see below); and y is a measure of the probability that a flood of intensity x will occur. For the analysis of streamflow data the parameter x is usually taken as a peak river flow (m^3/s) or the peak discharge in a given (short) time interval although peak river gauge levels have sometimes been used. The analysis is undertaken, most commonly, on the annual maximum series; that is, the series formed from the maximum value of x from each year for which records exist. Other alternatives have been used such as the peaks over threshold series which comprises all the recorded peak values of x over a selected threshold. This approach is more difficult to apply in practice because of the need to ensure that the peak values used are from hydrologically distinct events and that the threshold is not set too low[195].

As graphical analysis was the first to be developed it was found convenient to express the parameter y in a logarithmic form. It is now common practice to refer to y as the reduced variate and to define it by the expression:

$$y = -\ln(-\ln(P_x)) \qquad \text{or} \qquad P_x = \exp(-e^{-y})$$

Where P_x is the probability that a flood of magnitude x will not be exceeded. P_x can, in addition, be given as $(1 - 1/T)$ where T is the return period, in years, of a flood of magnitude x*.

As a result of the availability of electronic computers techniques of numerical analysis have gained prominence over graphical methods in recent years. But, as Cunnane (1975) argues in comparing the two approaches, the initial assumptions which are necessary in order to perform either numerical or graphical analyses should not be overlooked:

> The graphical method is said to be subjective because independent analysis would get different estimates from the same data; this is not true of numerical methods which are therefore said to be objective. Since objective methods are always preferable it is therefore customary to denounce the graphical method. However, the fact that some distribution has to be assumed is often overlooked in this comparison and the choice made between distributions must always have an element of subjectivity in it, notwithstanding the use of goodness-of-fit tests. If the true distribution were known (which is never the case) numerical methods would be preferable ... In the absence of such knowledge graphical methods

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* For $T < 5$ the simpler expression $y = \ln(T-0.5)$ gives values of y correct to three figures.

should not be lightly dismissed; a degree of difficulty tends to generate veneration for a method while simplicity tends to breed the familiar contempt. (p44)

In order to undertake a graphical analysis an initial assumption must be made about the most suitable value of y to assign to each member of the annual maximum series under study. If the annual maximum series extends over N years and takes the values $x_1 \ldots x_i \ldots x_N$ in order of ascending magnitude then the probability that a flood will not exceed the magnitude of the representative element, x_i, will lie between (i-1)/N and i/N. A number of alternative plotting positions in this range have been proposed; the one favoured by the *Flood Studies* team being that due to Gringorten (1963) which gives the estimated non-exceedance probability for element x_i as:

$$\hat{P}_i = (i-0.44)/(N+0.12)$$

This expression was chosen to ensure that the largest value lies as close as possible to the straight line relationship:

$$x = u + \alpha y$$

Where u and α are parameters whose values are to be determined for each case. This relationship was, in the past, commonly referred to as the <u>Gumbel distribution</u>. $\hat{P}_i$ may be substituted for P_x in the previous expressions used to define the reduced variate in order to obtain values of y_i against which values of x_i may be plotted on linear graph paper. Unfortunately, it would be incorrect to assume in all cases that the x, y data will adhere to the linear relation given above. The writers of the *Flood Studies Report*, however, after investigating a number of alternatives, concluded that if the curvature of the x, y relation is 'mild' then the Gringorten plotting positions would be sufficiently accurate[196]. It is shown in Appendix 6 that for the flood data at Cabora Bassa the curvatures are 'mild' and this plotting rule has, therefore, been applied in preparing flood frequency graphs for this thesis.

Numerical analysis is based on the assumption that a particular mathematical expression for the relation $x = f(y)$ will adequately represent each set of data once certain parameters have been evaluated. Various expressions were investigated by the *Flood Studies* team using data from the British Isles but none was found to be ideal. In general the three parameter functions were preferred and one of these, the general extreme value (GEV) distribution[197] was recommended for general use.

The GEV distribution takes the form:

$$x = u + \alpha(1 - e^{-ky})/k$$

where u and α are parameters, as used above, and k is the curvature which must also be determined for each set of data. It can be seen that as the value of k approaches zero the expression reduces to the Gumbel linear relation. This is now referred to as the GEV type-1 distribution. Negative values of k give rise to a curve which tends towards the lower limit of $x = u - 10\alpha/3$ whilst the upper values of x are unbounded. This is referred to as a GEV type-2 distribution. The GEV type-3 distribution, which occurs with positive values of k, is unbounded at the lower end but tends towards the upper limit, $x = u + 10\alpha/3$.

Jenkinson (1969) has drawn attention to the limitations of the GEV method, particularly in cases where evaluation of the three parameters indicates that a type-2 distribution should be used. The unbounded flood peaks are, he suggests, a physical impossibility. He proposes that, in such cases, the relation may be complex beginning, perhaps, as type-2 but changing to type-3 as y increases.

Application of the GEV distribution involves the use of the maximum likelihood procedure to determine values for the three parameters. If rigorously applied this procedure requires considerable computation which is rarely undertaken except on a large electronic computer. There are, however, simpler techniques which can be used to provide approximate results. Jenkinson (1969) found the most reliable of these to be the method of sextiles*. The annual maximum series, arranged in order of

* Full details of the method together with tabulated values to be used in its application may be found in the reference.

ascending x, is divided into sextiles and the mean of each sextile is calculated. These are assigned the symbols w_1 to w_6. The value of the parameter k in the GEV function can be determined from a table in which theoretical values of k are related to values of the term $(w_2 - w_1)/(w_6 - w_5)$. Part of this table is reproduced in Table 8 below and is used in Appendix 6 to justify the use of the Gringorden plotting positions in the flood frequency graphs contained in this thesis. The parameters u and α can also be calculated from values of the mean and standard deviation of the data series.

Table 8: Selected values of the curvature parameter, k, in the GEV distribution as determined by the 'method of sextiles'.

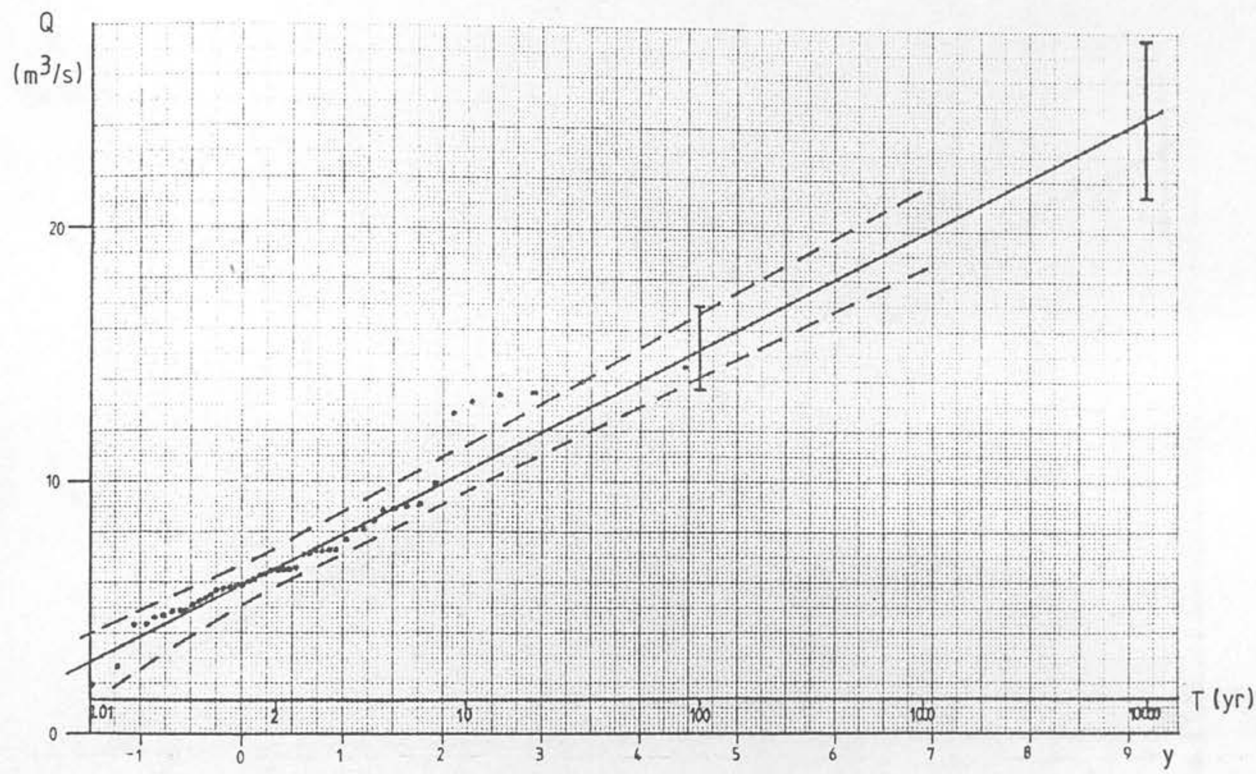
k	-0.2	-0.1	0	0.1	0.2
$\frac{w_2 - w_1}{w_6 - w_5}$	0.23	0.32	0.43	0.58	0.79

Source: Jenkinson (1969)

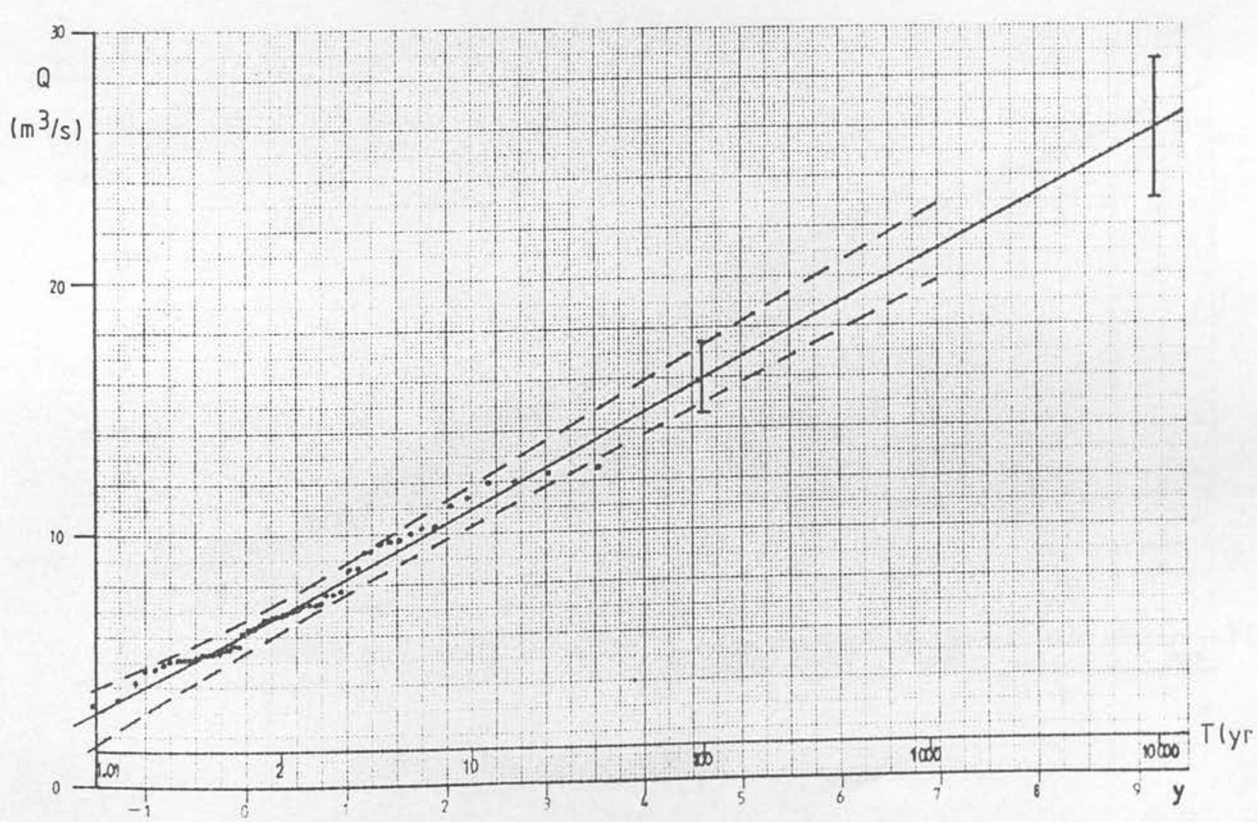
The discrepancies between the sets of data used in two important recent studies of flood inflows to Lake Cabora Bassa are highlighted in Appendix 6. It also draws attention to the scale of the possible error arising from the use of short data records for the estimation of extreme floods. For these reasons it is unlikely that numerical analysis would, in this instance, provide results which would be significantly more reliable than those obtained by graphical methods. Graphical methods are, therefore, considered adequate for the purposes of the present study. The results of graphical analysis of the frequency of extreme floods of one-, two- and three-month duration from the two separate sets of annual maximum data discussed in Appendix 6 are shown in Figures 19 to 21.

c) Choice of design flood standard: The choice of the magnitude of design flood to be used in determining the appropriate operating procedures for a reservoir involves an assessment of the risk which would be associated with floods of particular frequencies. Unfortunately,

Figure 19: Flood frequency analysis of annual maximum one-month duration Cabora Bassa 'natural' discharges.

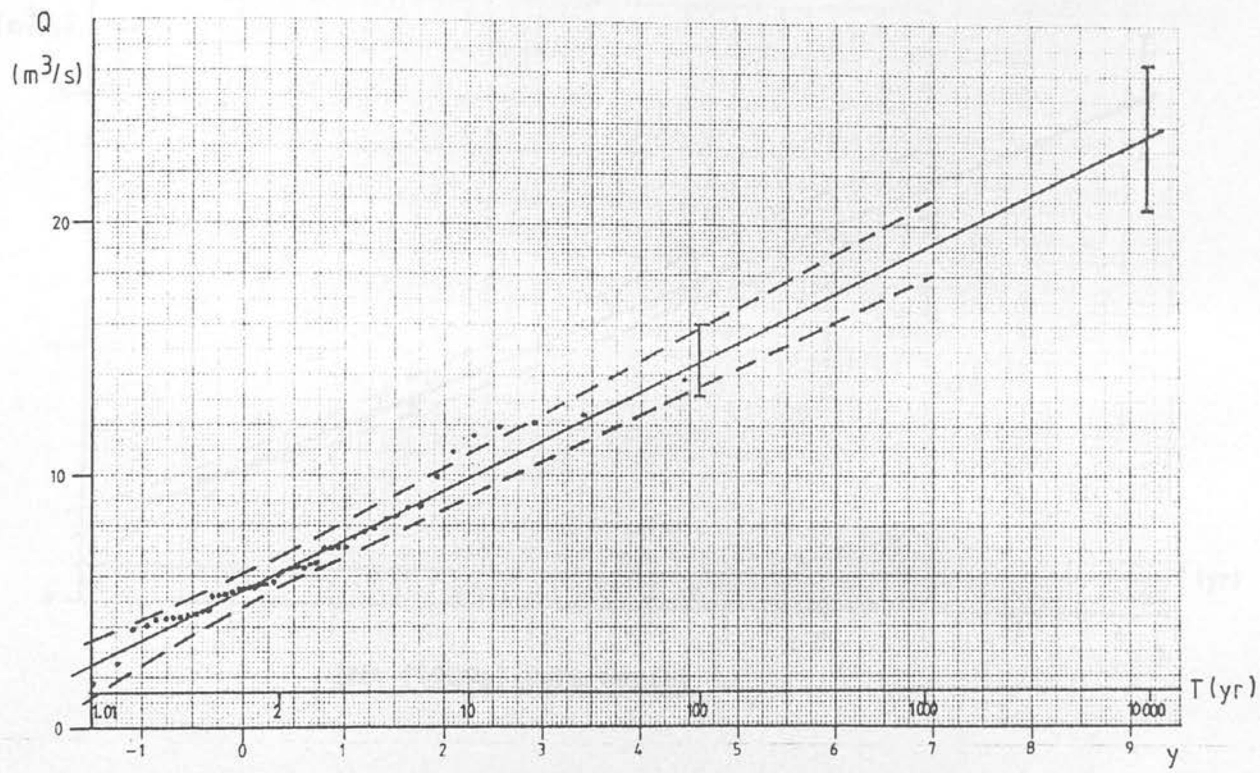


DNA (1980a) data series

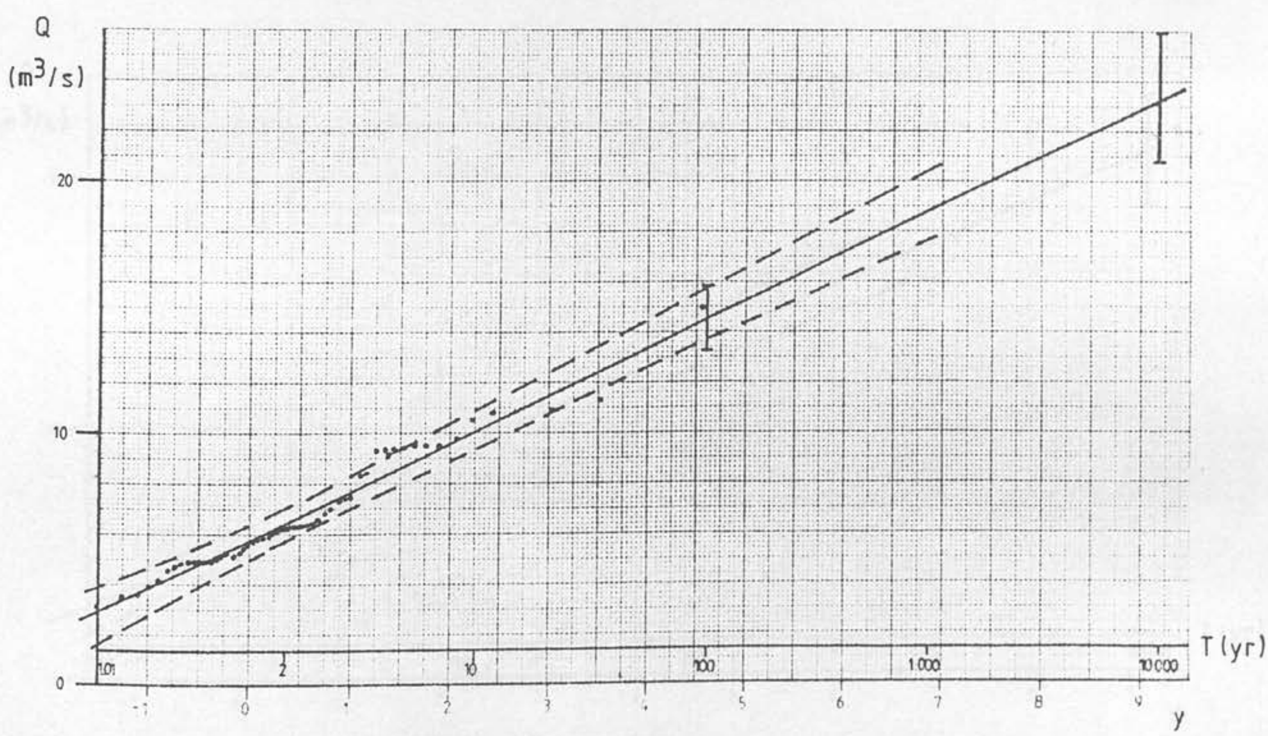


RPT (1980) data series

Figure 20: Flood frequency analysis of annual maximum two-month duration Cabora Bassa 'natural' discharges

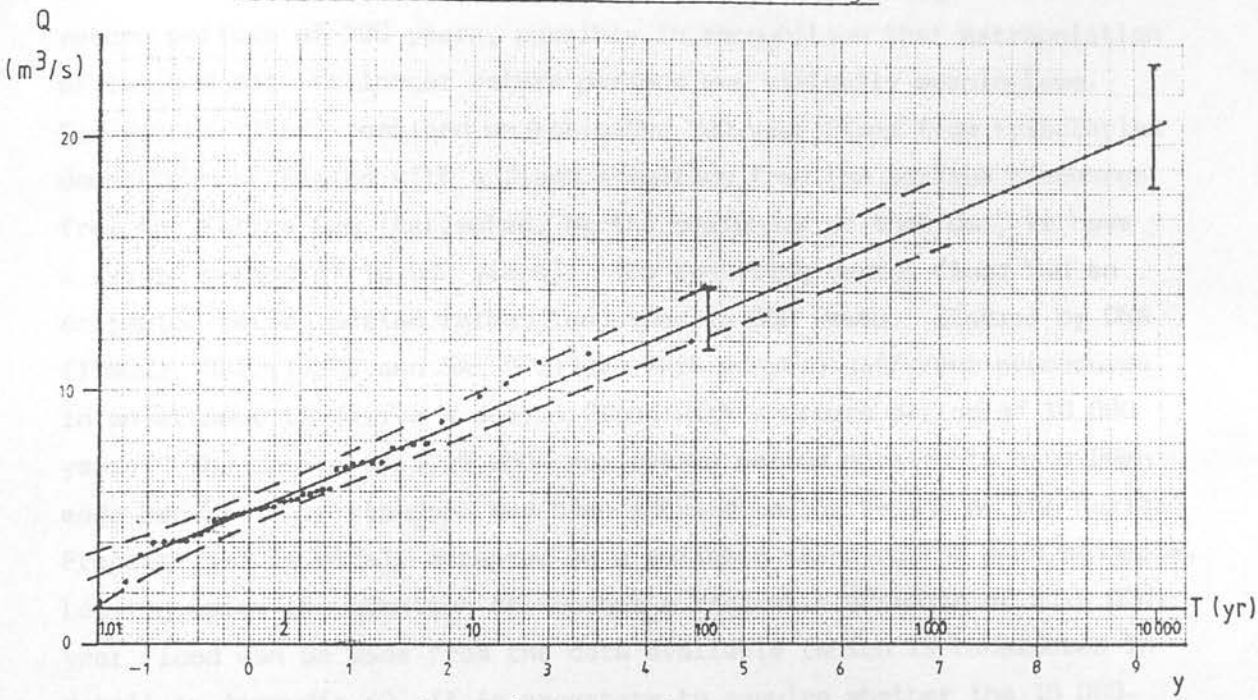


DNA (1980a) data series

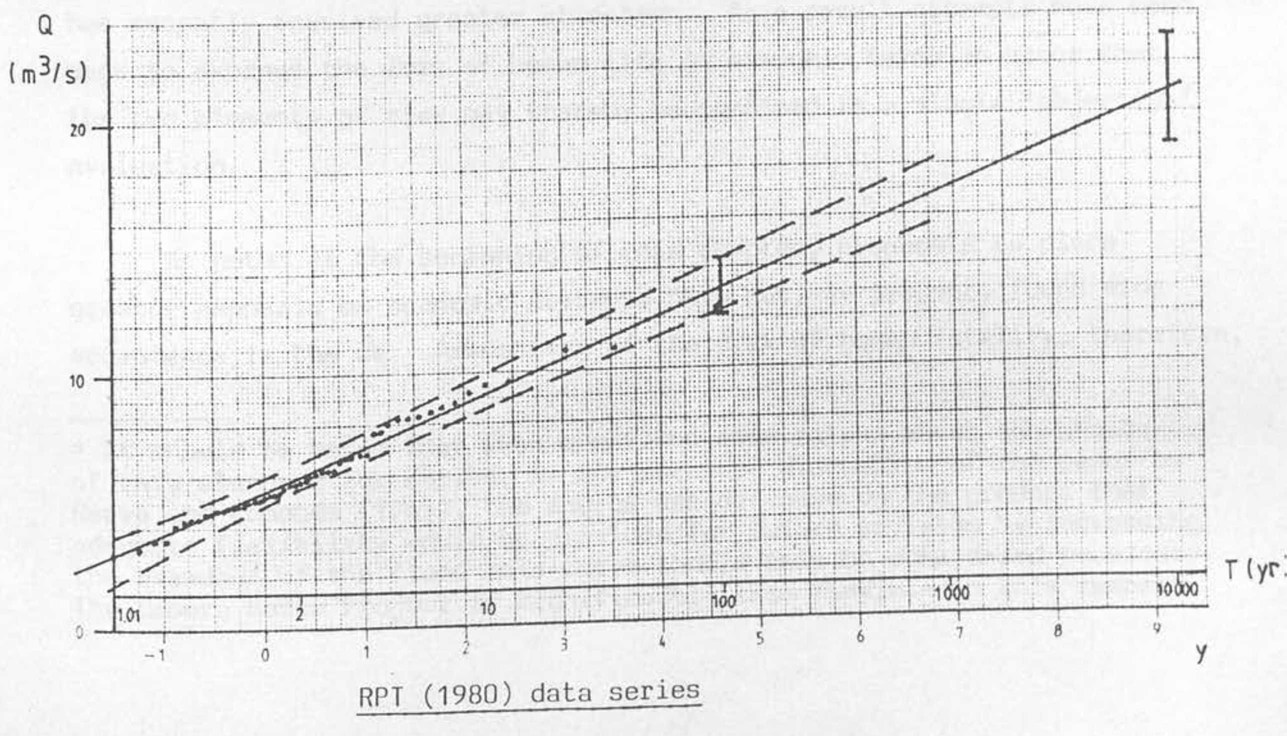


RPT (1980) data series

Figure 21: Flood frequency analysis of annual maximum three-month duration Cabora Bassa 'natural' discharge



DNA (1980a) data series



RPT (1980) data series

few of the hydrological studies undertaken for the Cabora Bassa Project have discussed the basis on which the design floods adopted were selected. Studies undertaken prior to 1968 adopted design floods with return periods of 500 years, possibly in recognition that extrapolation of limited data to longer return periods was virtually meaningless. Dos Santos (1968) combined an estimated 500-year flood from tributaries downstream of Kariba with a flood resulting from the maximum discharge from the Kariba Dam (estimated, by the designers of that dam, to have a return period of 10 000 years). The resulting design flood had an estimated return period rather less than 10 000 years. Studies by DNA (1980a), RPT (1980) and SWECO (1982) each adopted different procedures in an attempt to derive a design flood with a return period of 10 000 years. The choice of a 10 000-year return period appears to have been made because this standard had been adopted in the design of the Kariba Project* and is widely accepted as a suitable standard for such projects. Leaving aside the question of whether a realistic estimate of a 10 000-year flood can be made from the data available (which is considered in detail in Appendix 6), it is necessary to enquire whether the 10 000-year flood is an appropriate standard to adopt.

In considering the risk associated with the adoption of a particular design flood standard a distinction is generally made between risk of fatality and economically quantifiable risk. Since the latter appears to offer a more objective basis for selecting a design standard it has recently received greater attention. As a result attempts have been made to express the loss of human life in economic terms in order that the two elements of risk may thereby be combined in a single 'objective' evaluation.

As noted at the beginning of this chapter, proposals to place greater emphasis on economic criteria have not, at present, found wide acceptance in the UK. Assessment of the risk of human fatality, therefore,

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* It should be noted that when questions were raised about the choice of this standard for Kariba, in the recorded discussion of the paper by Reeve and Edmonds (1965), the choice was defended on the grounds that adequate flexibility would be provided for future revision by increasing the drawdown of the flood rule curve should this be considered necessary. The Cabora Bassa Project is significantly less flexible in this respect.

retains priority in the selection of design flood standards.

In the past, it has been widely accepted by engineers in the UK that, in the design of spillways, no loss of life can be contemplated and that, therefore, the PMF should be used in design flood calculations[198]. Only where there is no foreseeable danger to human life would a lower standard based on the results of an economic appraisal be considered justified. Accounts of risk analysis in other spheres of human activity suggest, however, that the attempt to reduce the risk of fatality as close as possible to zero is unrealistic. For example, Pochin (1975) in a paper discussing health risks, particularly from radiation, argues that:

> in whatever we do and in whatever we refrain from doing we are accepting risk. (p184)

His paper seeks to evaluate the risk of fatal and non-fatal injury from certain types of activity*. However, he questions whether such evaluations are necessarily of use to planning authorities who are faced with the question:

> if some degree of risk is unavoidable and if, as in all cases, the level of risk can to some extent be influenced ... what numerical level of safety should be required? Or, to put the question more brutally, what maximum number of deaths should be authorized? (p189)

His answer is to propose that new risks should be:

> controlled so as to be at least as safe and therefore 'acceptable' as in conventional activities. (p189)

Quantitive application of Pochin's proposal would, however, be extremely

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* One of the categories of occupational risk which Pochin considers is, in fact, dam construction work. His approximate figures for Cabora Bassa (50 deaths in a workforce of 3 000 over a period of 5 years) and the Aswan High Dam (over 100 deaths per year in a workforce of 35 000) suggest rates of risk of the order of 3 500 deaths/million/year (d/M/y). This is very high in comparison with rates varying from 3 d/M/y to 160 d/M/y for deaths attributed to 'accidents' in British industry during the 1960s and is comparable to those of one of the most dangerous activities cited, deep-sea fishing.

difficult in the case of a dam such as Cabora Bassa. It would involve, amongst other things, assessing the risk of dam overtopping and the subsequent risk of dam failure, routing of the dam-break discharge through the floodplain, assessing the number of direct and indirect fatalities which might occur, given the emergency provisions currently available, as well as determining the 'acceptable' level of risk to inhabitants of the valley from existing causes such as drought, disease and 'natural' floods.

A number of engineers have suggested that design flood standards in developing countries need not be as exacting as those in an industrialized country such as the UK[199]. Their arguments are based on the recognition that the population in such regions is already subjected to a high level of risk and that the construction of a dam would bring benefits such as irrigation which would reduce that risk. This suggestion highlights a dilemma, facing countries seeking to industrialize, concerning the risk which the introduction of new technological products and processes may bring. On the one hand, outside consultants or suppliers may 'take advantage' of less stringent control regulations, or less articulate public opinion in such societies, and advocate standards which are below those currently required in industrialized countries. On the other hand, to accept only the technologies which meet the highest safety standards involves the underdeveloped country in an extra economic burden which was not borne by the industrialized countries in the early stages of their own industrialization. Nevertheless, it is unlikely that any industrialized country, in its early stages of development, possessed a single work of technology which could have produced consequences as devastating as those which would affect the people and economy of Mozambique should the Cabora Bassa Dam fail. Careful consideration of the choice of the design flood is, therefore, essential in such a case.

In the absence of the detailed and costly studies which would be required in order to place the evaluation of flood risk for the Cabora Bassa Project on a more rational footing, engineers have been compelled to apply general standards from other countries. Of these, the report published by the ICE (1978), deserves particular note since it provides the basis for current practice in the UK. An important feature of the report's recommendations is the categorization of dams according to the risk which they pose to human life. In this four-part classification the Cabora Bassa Dam would almost certainly be placed in category A, where a breach of the dam would endanger lives in a community downstream. The general design flood standard recommended for such dams is the PMF although 'if rare overtopping is tolerable' the design flood should have a return period of 10 000 years or have a magnitude 0.5 x PMF whichever is larger*. It was concluded earlier in this chapter that overtopping cannot be assumed to be tolerable at Cabora Bassa without further investigation of the possible consequences. Thus, ideally, the PMF should be used as the design flood according to these criteria.

In Britain the PMF is calculated from estimates of the maximum precipitation, a technique which, as noted above, would not be practicable in the Zambezi basin. Alternatively, engineers have, in the past, attempted to estimate values of the PMF from the results of a frequency analysis of annual maximum discharge series. Bass (1975) has shown how unsatisfactory many such attempts had been; chosen return periods varied from 100 000 to over a million years whilst, in response to the suggestion that the PMF could be obtained by multiplying the 150-year flood by a given factor, factors varying from 2.8 to 8.9 had been proposed. Bass recommended the use of a return period of a million years and a factor by which the 150-year flood should be multiplied of 7.0. At the same seminar, however, Griffiths and Berry (1975) quoted values for the 'estimated maximum flood' corresponding to return periods of 35 000 years. The discrepancy between the various values suggested above in estimating the PMF may be illustrated by reference to the three-month duration annual maximum flood series for Cabora Bassa shown in Figure 21. In this and other studies values of the 10 000 year flood have been estimated for use in the flood rule curve calculations. If

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* Law (1980) includes a table giving a similar classification of dams which apparently provides the basis for design flood specification in Korea. For category A (which comprises dams financed by large international loans as well as those which might endanger communities), the general standard is, again, the PMF. However, the standard used for 'concrete dams' in this category is a 5 000-year flood. In India, according to Gole and Krishnamurthy (1979), classification is based solely on reservoir capacity. For reservoirs of more than 50 x 10^6 m^3 capacity (Cabora Bassa's is 1 000 times greater than this), the standard applied is always the PMF.

one of the other flood standards, described above, had been used instead, the value of the three-month duration design flood would have been increased by the following, approximate, amounts: 35 000-year return period, 10%; 100 000 year return period, 20%; a flood 2.8 times greater than the 150-year flood, 80%; a flood 7 times greater than the 150-year flood, 360%. In the rule curve calculations which follow it will be shown that to accommodate a design flood 20% greater than the estimated 10 000-year flood at Cabora Bassa would necessitate a drawdown so large that power generation would be impaired. A 30% increase would require drawdown below the reservoir's minimum operating level (295 m O.D.). Thus the maximum flood which the Cabora Bassa Project could regulate, under present conditions, appears to be significantly smaller than values which would find general acceptance as realistic estimates of the PMF.

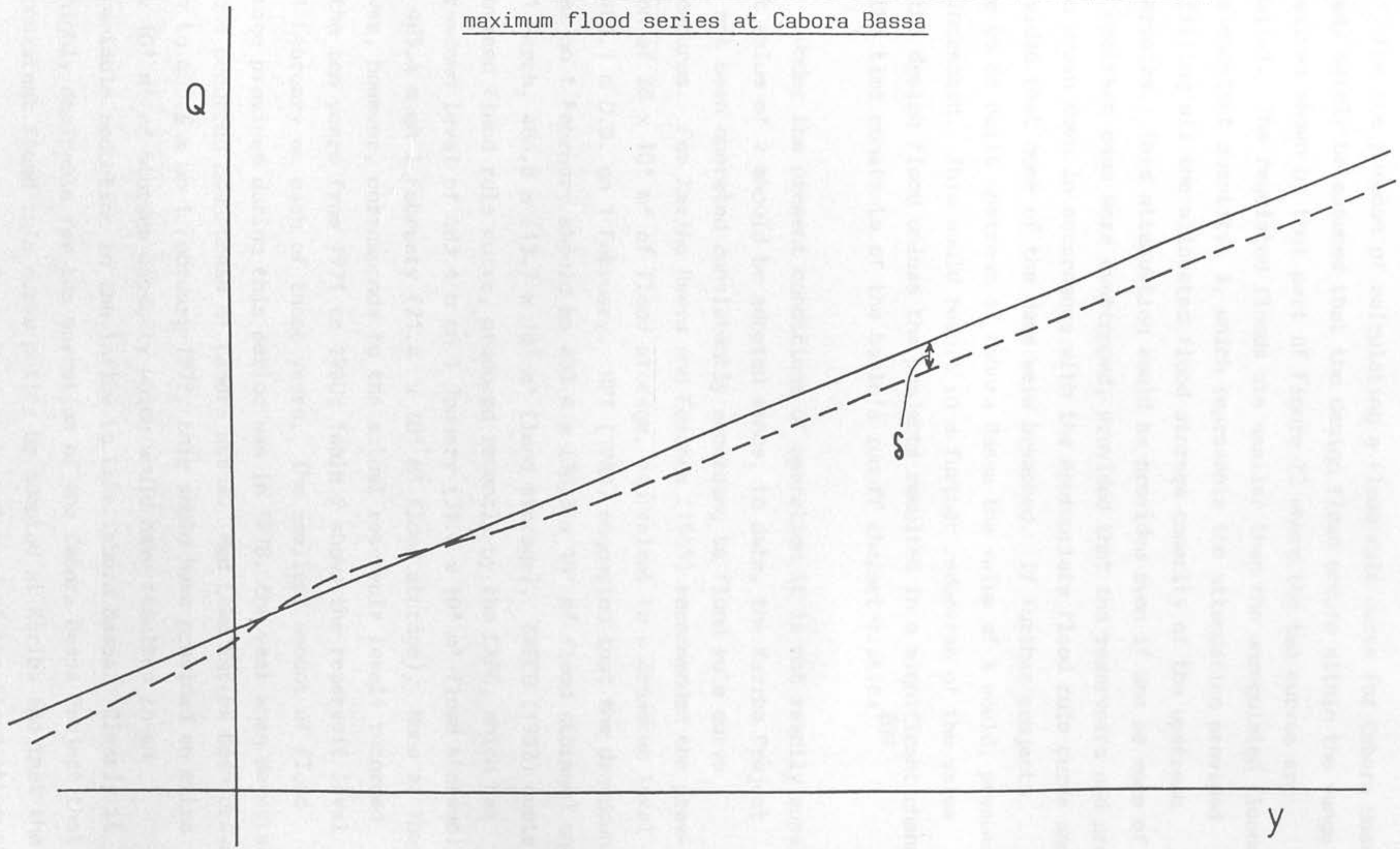
Although the foregoing discussion may appear to be of little practical relevance in view of the impossibility of providing accurate estimates of even a 10 000-year flood from the available data it should be noted that such a flood has a 1% probability of occuring if the dam stands for 100 years. Furthermore, in a number of cases, floods which were previously considered to have an extremely low probability of occuring have been recorded. Gruner (1963), for example, cites the case of a project in Uruguay which was designed to accommodate a 1 000-year flood on the basis of twenty-seven years of data. Within fourteen years of completion it had suffered a flood which would have been considered a 500 000-year flood on the basis of the design data.

In the simulations and discussion within this thesis estimated values for the 10 000-year flood are used as the basis for the design flood at Cabora Bassa. Although this is in accordance with the standard adopted by all the major studies undertaken since 1975, and with the standard adopted at Kariba, the foregoing discussion illustrates its possible inadequacy. In particular, the design standards applied in the UK suggest that a more conservative standard should be adopted at least until such time as a more detailed assessment can be made of the possible effects of overtopping the dam. On the other hand, unless the discharge capacity of the dam is increased, an increase in the value of the design flood of only 20% could not be accommodated without prejudicing power production. It seems probable, therefore, that the 10 000-year flood will be retained as the design flood standard for the time being. The additional risk could be reduced by provision of procedures for the evacuation of the population should the imminent threat of dam overtopping arise. Fortunately in such a large catchment it should be possible to provide adequate warning of a flood of this magnitude because of the long flood travel times.

d) The influence of developments upstream: The value of the design flood at Cabora Bassa may be influenced in a number of ways by developments in its catchment area. In the long-term, significant changes may occur in the runoff characteristics of the catchment as a result of changes in land use and vegetation. Such effects are discussed in Appendix 6. In the short-term the most important influence is the regulation of river discharges provided by reservoirs upstream. This effect is best illustrated by studying the changes which river regulation produces in the annual maximum flood series, such as those of Figures 19-21. For the purposes of this illustration it is assumed that the series of unregulated discharge data obeys a GEV type-1 (linear) distribution when plotted against the reduced variate, y. (This assumption will not affect the results).

Upstream regulation will affect the flood discharges over almost the entire series. In the driest years regulation is likely to reduce the annual maximum three-month floods since the natural floods, such as they are, will be stored in the upstream reservoirs to provide electrical power at a later date. In the wettest years, assuming the reservoirs are operated according to a reliable flood rule curve procedure, the annual maximum three-month floods will also be reduced, the amount being equal to the total storage capacity reserved in those reservoirs for flood control. Between these extremes the effect will depend on the operating policy adopted for the upstream reservoirs. If, as RPT (1980) suggested might occur at Kariba, the annual drawdown is achieved by discharging excess water in the months of December and January, these discharges may augment the natural floods and produce an annual maximum three-month flood in excess of that which would have occurred in the unregulated river. These effects are shown schematically in Figure 22.

Figure 22: Schematic representation of the effects of upstream river regulation on the annual maximum flood series at Cabora Bassa



For the purpose of calculating a flood rule curve for Cabora Bassa it may safely be assumed that the design flood occurs within the range of values shown by that part of Figure 22 where the two curves are parallel. The regulated floods are smaller than the unregulated floods by a constant quantity, ∂, which represents the attenuation provided by filling all the allocated flood storage capacity of the upstream reservoirs. This attenuation would be provided even if one or more of the upstream dams were overtopped, provided that the reservoirs had previously been drawn down in accordance with the appropriate flood rule curve and provided that none of the dams were breached. If further projects were to be built upstream of Cabora Bassa the value of ∂ would, presumably, be increased. This would result in a further reduction of the value of the design flood unless the projects resulted in a significant change in the time constants of the basin's runoff characteristics[200].

Under the present conditions of operation it is not readily apparent what value of ∂ should be adopted since, to date, the Kariba Project has not been operated consistently according to flood rule curve procedures. For Kariba Reeve and Edmonds (1965) recommended the provision of 28×10^9 m³ of flood storage, equivalent to a drawdown level of 484.1 m O.D. on 1 February. RPT (1980) suggested that the drawdown level on 1 February should be 483.6 m (30.8×10^9 m³ flood storage) and on 1 March, 486.8 m (13.7×10^9 m³ flood storage). SWECO (1982) quote a revised flood rule curve, produced recently by the CAPC, which has a drawdown level of 483.4 m on 1 January (31.8×10^9 m³ flood storage) and 485.4 m on 1 February (21.4×10^9 m³ flood storage). None of these curves, however, corresponds to the actual reservoir levels recorded in the ten years from 1971 to 1980; Table 9 shows the reservoir level on 1 February on each of these years. The smallest amount of flood storage provided during this period was in 1978, the year when devastating floods occurred downstream of Cabora Bassa. Had Lake Kariba been drawn down to 483.6 m on 1 February 1978, this would have provided an extra 19×10^9 m³ of storage capacity which would have resulted in an appreciable reduction in the inflow to Lake Cabora Bassa. Clearly it is highly desirable for the operation of the Cabora Bassa Project that a consistent flood rule curve policy be adopted at Kariba and that the operators of the Cabora Bassa Project be informed of the flood attenuation which would thereby be provided. For the purposes of this thesis it has

Table 9: Reservoir levels at Kariba on 1 February

(Source: CAPC Annual Reports)

YEAR	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
RESERVOIR LEVEL (m.O.D.)	484.2	493.7	483.3	484.6	486.6	484.7	485.0	487.3	486.1	484.7
FLOOD STORAGE PROVIDED* ($m^3 \times 10^9$)	27.6	30.2	32.2	25.4	14.9	25.0	23.4	11.1	17.6	25.0

* Assuming a maximum retention level of 489.3 m

been assumed that the curve of RPT (1980) will be adopted thus providing 17.1×10^9 m^3 flood storage in the month of February and 13.7×10^9 m^3 in the month of March (30.8×10^9 m^3 for the two months combined). It has been suggested, in RPT (1980), that without the use of such a curve the Kariba Dam is in danger of being overtopped. For this reason RPT suggested providing an extra 10×10^9 m^3 flood storage capacity at Cabora Bassa to provide a small margin of safety which would, at least, allow extra time for the population downstream of Cabora Bassa to be evacuated should it be considered necessary.

For the Kafue Project which provides the only other major storage capacity upstream of Cabora Bassa full details of its flood storage capabilities are not provided in any of the design flood studies for Cabora Bassa. Nevertheless, RPT (1980) assumed that a flood storage capacity of 5×10^9 m^3 would be available at the Itezhitezhi reservoir on 1 February. This value has been adopted for the purposes of the present study.

e) The maximum reservoir level: Previous studies of the Cabora Bassa Project assumed different values for the maximum retention level of the reservoir, see Figures 10-12. In the *Plano Geral* the proposed level was 325 m O.D. The majority of studies have used a value of 329 m (2 m below dam crest) whilst SWECO (1982) proposed a level of 330.5 m (0.5 m below dam crest). Even between the studies which use the 329 m level there are differences: dos Santos (1968) maintained that this level would be reached very rarely, with a probability considerably less than 1:100 years, (326 m being the normal maximum), whereas in the studies of RPT (1979 and 1980) the operating procedures proposed would allow the 329 m to be reached relatively frequently. The difference arises because dos Santos assumes that large discharges will be made at levels below the flood rule curve whereas RPT assumes that only moderate discharges will be made until the flood rule curve levels are reached. The simulations in the present work are based on the latter assumption.

The controversy over the maximum retention level of Lake Cabora Bassa has international implications. In December 1970, the Zambian Government stated its intention of seeking compensation from the Portuguese authorities on the grounds that:

> ... it is obvious that Cabora Bassa will submerge the Mpata Gorge project site and no development will be possible in this gorge. It is also expected that a large area of Zambia will be flooded. The level of the tail water near Kariba may also rise at certain periods of the year affecting generation in the existing project[201].

In a reply, prepared by Hidrotécnica Portuguesa, it was stated that Cabora Bassa's normal maximum level would be 326 m, about 90 m lower than the level which the Zambian communication appeared to imply. Hidrotécnica Portuguesa admitted, however, that in the event of a 100-year tributary flood coinciding with a 10 000-year discharge from Kariba the level of Lake Cabora Bassa would reach 329 m. Nevertheless, it was argued that river levels at Zumbo would produce similar flood inundation from such flows even without the dam.

Although during the first five years of operation of the Cabora Bassa Project the maximum reservoir level never exceded 328 m a significant change in the maximum water levels at Zumbo occurred. From the commencement of gauging at Zumbo, in 1950, until the closure of the Cabora Bassa Dam, in 1974, a water level in excess of 327 m was recorded on only two occasions[202]. From 1975 to 1979 the reservoir operation caused water levels at Zumbo to pass this level in three of the five years, on one occasion for a period of two months, see Figure 23.

Although the foregoing discussion suggests that the influence of Lake Cabora Bassa on water levels upstream may be greater than was initially supposed, it does not provide an adequate basis for determining a suitable value for the maximum retention level of the reservoir. To do so would require a thorough survey of the area which would be affected in Mozambique, Zambia and Zimbabwe at various reservoir levels. Study of the effects of the high reservoir levels in March and April, 1978, would provide valuable information for such a survey. During that period there were suggestions that disruptive flooding had occurred in the Zambian town of Feira[203]. It is probable, therefore, that such a survey would reveal that frequent retention at levels of 329 m would not be acceptable without international agreement and without the introduction of measures to relocate or protect the population which would be affected. SWECO's suggestion of a 330.5 m retention level would be still less acceptable. It should be noted that the possible deposition of sediment at the head of the reservoir, see Chapter 5, would exacerbate the situation.

The maximum retention level used in the present calculations is 329 m. The possible effect on the flood rule curve of adopting the lower maximum retention level, of 327 m, is also investigated. Should the lower level be found to be necessary in order to prevent upstream flooding it would place a further constraint on the system and necessitate a thorough revision of the conclusions of the reports by RPT and, to a greater extent, SWECO (1982).

f) Other factors: The following factors might also influence the form of the flood rule curve at Cabora Bassa.

Short duration flood peaks: RPT (1980) noted the danger that, by using time intervals of one month in the numerical simulations, the possible effects of short duration flood peaks would be overlooked. To allow for such effects RPT increased the assigned flood storage by 10% in preparing the final flood rule curve. This procedure has not been repeated here because it does not appear to offer a realistic way

Levels of Lake Cabora Bassa with corresponding levels of Zumbo river gauge

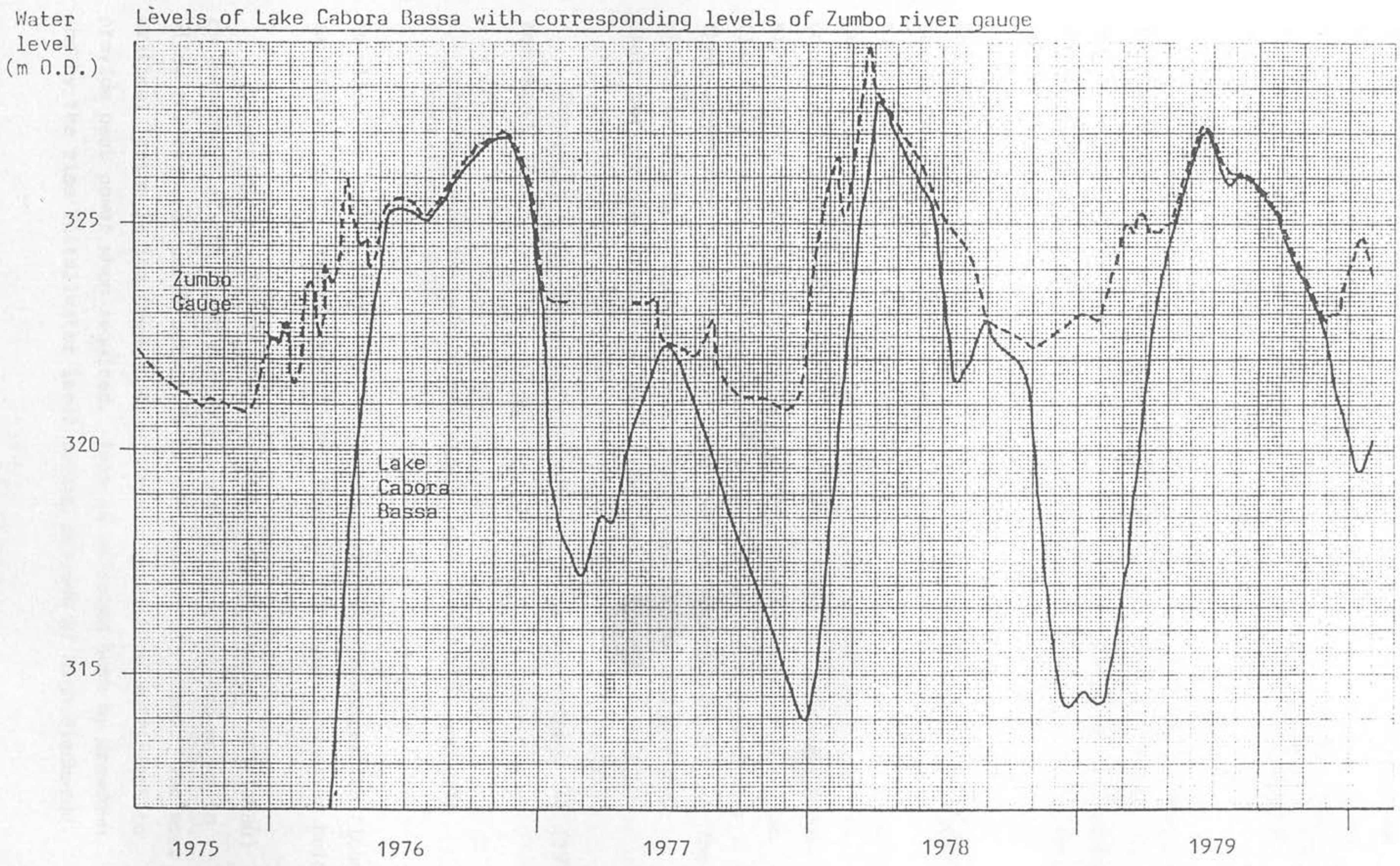


Figure 23

Source: DNA files, Maputo

of allowing for such peaks. A sounder approach would be to increase the flood storage capacity in each of the critical months by a given amount, say 2×10^9 m^3. Far greater accuracy could be achieved if it were possible to repeat the simulations using shorter time intervals but the available data does not allow this.

Intra-annual distribution of the design flood: One of the reasons for the differences between the flood rule curves shown in Figures 10 and 11 is that they are based on different assumptions about the intra-annual distribution of the design flood. For the curves of dos Santos and DNA (fixed month method) it is assumed that the maximum one-month duration flood will occur in March whereas for the curves of RPT and DNA (maximum month method) the one-month flood is assigned to February, see Table 11 below. The discussion in Appendix 6 shows how such differences have arisen from the analysis of different sets of input data. This approach provides an inadequate basis for resolving the uncertainty as to which of these two months should be adopted. Likewise, there is some uncertainty as to whether the two-month duration flood would occur in February-March or March-April and whether the three-month flood would occur in January-March or February-April. The effect on the flood rule curves of these alternative design flood distributions has, therefore, been taken into account.

Damage to a discharge gate: *Floods and Reservoir Safety*, ICE (1978), recommends that:

> checks should be made on potential flood levels with one gate immobilized. (p19)

To allow for such a possibility would require a more conservative flood rule curve, as is demonstrated in the appropriate simulation given below.

Maintaining a minimum net head for power generation: RPT (1980) recommended that the flood rule curve should be calculated so as to allow the required power output to be achieved at all times. The most critical factor is the need to maintain a minimum head sufficient to provide peak power when required. This is affected both by drawdown and by the rise in tailwater level during periods of high discharge.

Table 12 gives the results of the present flood rule curve calculations with the mean net head* as calculated for each of the critical months. According to RPT, these values should be greater then 99.5 m so as to ensure that the requirement for peak power can be met, and greater than 87.5 m to provide the continuous (baseload) output. Although not explicitly stated, the value of minimum head for peak power appears to be derived from RPT's most conservative assumptions about generating and electrical transmission efficiencies, whereas for the baseload calculations less conservative assumptions were made. On the basis of these less conservative assumptions the minimum head required to meet the peak demand should be reduced to 97.5 m. Whichever of the values, 99.5 m or 97.5 m, is used it can be seen from Table 12 that inflows approaching those of the design flood would be likely to result in some restriction of the peak power output in almost every case considered. Restriction of baseload output also occurs in two of the calculations.

Turbine discharges: The two flood rule curves shown in Figure 10b were calculated on similar assumptions except that the more recent one, which simulated the operation of the proposed power station in the north bank, was based on the assumption that the total discharge capacity of the dam would increase as a result of the additional turbine discharges. It may be seen from Figure 10b that this assumption led to a considerable relaxation of the flood rule curve conditions.

Conversely, if power generation were interrupted the dam's discharge capacity would decrease and additional reservoir storage would be required if the dam were not to be overtopped by the design flood. This situation is investigated further in the rule curve calculations below. The assumption that turbine discharges should be ignored is by no means unreasonable. ICE (1978) recommends that such an assumption should be made in all flood rule curve calculations. In the case of Cabora Bassa there is a real possibility that complete shutdown of the power station might occur because of the project's dependence on the single major load centre in the RSA. On a number of occasions the transmission lines

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* It should be stressed that these values are monthly means and the head will fall below the stated value for short periods during the month.

to the RSA have been sabotaged, see Chapter 4, and, even if this possibility could be dismissed, there remains the risk that the meteorological conditions which would produce inflows of the magnitude of the project's design flood might cause damage to the electrical transmission system and prevent ready access to repair any faults that might occur. Of the previous studies, only SWECO (1982) draws attention to the possible danger of loss of load leading to shutdown of the turbines but even that report fails to investigate the possible effect that this would have on the flood rule curve. In fact the turbines may account for over 10% of the total discharge and to allow for their complete shutdown a large amount of additional flood storage would be required.

Wave action: It is customary to allow additional 'freeboard' at a dam to prevent it from being overtopped by waves. At Cabora Bassa it is unlikely that such freeboard will be required over that already allowed for by the maximum retention level of 329 m, as specified above, since the dam is in a sheltered gorge isolated from the main body of the lake and the prevailing wind direction is away from the dam.

g) Flood rule curve calculations: A series of flood rule curve calculations was undertaken to investigate the effect of the various factors discussed above. A set of conditions was selected for an initial calculation after which the effects of various changes in these conditions were assessed separately. A description of these calculations is given in Table 10. Details of the design flood values used in each calculation are given in Table 11 together with values used in previous studies. The method by which values of the corresponding flood rule curves were obtained from this data is set out in Appendix 7 using the conditions of the initial calculation as an example. A summary of the results obtained is given in Table 12 together with the flood rule curve values obtained from previous studies.

The flood rule curve calculations were not intended to produce a new curve which should be used in preference to all curves previously proposed but, rather, to investigate the main characteristics of the

Table 10: Description of the flood rule curve calculations

No.	General discription	Detailed descriptiom
1.	Initial calculation	10 000-year flood, derived from Figures 19-21, attenuated by storage at Kariba (17×10^9 m^3 in February and 13×10^9 m^3 in March) and at Itezhitezhi (5×10^9 m^3 in February); continuous power output of 1605 MW; maximum retention level, 329 m
2.	Allowance for error in estimation of 10 000-year flood	Design flood based on the upper values of the 90% tolerance bands in Figures 19-21
3.	Design flood with return period greater than 10 000 years	Estimated values of 10 000-year flood increased by 20%
4.		Estimated values of 10 000-year flood increased by 30%
5.	Alternative intra-annual distribution of design flood	Maximum one-month flood in February
6.		Maximum two-month flood in March-April
7.		Maximum three-month flood in January-March
8.	Reduction in upstream attenuation of floods similar to the situation in 1978	No flood storage capacity reserved at Itezhitezhi and flood storage capacity reduced to 6×10^9 m^3 in February and 5×10^9 m^3 in March at Kariba
9.	Reduced maximum retention level	Maximum retention level, 327 m.
10.	Damaged discharge gate	One discharge gate immobilized
11.	Loss of major load from electrical power system	No discharges through turbines

Table 11: Design flood data based on annual maximum series of unregulated inflows

Flood rule curve calculation	One-month flood m^3/s; month	Two-month flood m^3/s; months	Three-month flood m^3/s; months	Resulting design flood inflows - unregulated ($m^3 \times 10^9$)			
Present study				Jan	Feb	Mar	Apr
1, 8-11	25 100 Mar	23 500 Feb-Mar	20 800 Feb-Apr		53	67	40
2	28 600 Mar	26 500 Feb-Mar	23 200 Feb Apr		58	77	43
3	30 100 Mar	28 200 Feb-Mar	25 900 Feb-Apr		63	81	48
4	32 600 Mar	30 600 Feb-Mar	27 000 Feb-Apr		69	87	52
5	25 100 Feb	23 500 Feb-Mar	20 800 Feb-Apr		61	59	40
6	25 100 Mar	23 500 Mar-Apr	20 800 Feb-Apr		36	67	57
7	25 100 Mar	23 500 Feb-Mar	20 800 Jan-Mar	42	53	67	
Previous studies							
dos Santos (1968)* and H.P. (1969)	22 400 (18 900) Mar	21 600 (18 900) Feb-Mar	19 700 (18 000) Feb-Apr		50 (46)	60 (51)	42 (42)
DNA (1980a)* maximum months	29 400 (23 500) Feb	25 900 (21 300) Feb-Mar	22 500 (19 400) Feb-Apr		71 (57)	61 (52)	41 (41)
DNA (1980a)* fixed months	29 400 (23 500) Mar	26 300 (21 700) Feb-Mar	22 600 (19 500) Feb-Apr		55 (48)	79 (63)	40 (39)
RPT (1980)	27 600 Feb	22 800 Feb-Mar	21 000 Feb-Apr	23	67	49	45

* Unregulated flows were not specifically calculated in these reports. In each case the design flood value given had been attenuated by storage at Kariba. These attenuated values are given in parentheses. The writer has estimated the equivalent unregulated flows which appear in the table.

Table 12: Results obtained from flood rule curve calculations

Calculation	Values of flood rule curve - reservoir level on 1st of month (m O.D.)				Mean net head in month (m)			
	Jan	Feb	Mar	Apr	Jan	Feb	Mar	Apr
Present study								
1		326	324	329		97	98.5	100.5
2		317.5	318	328		90.5	95.5	100
3		308	312.5	326		84	92	99
4		(295)*	305.5	324		-	88	98.5
5		326.5	327	329		98.5	99.5	100.5
6		324	314.5	322		92	91	97.5
7	325.5	326	324	329	97.5	97	98.5	
8		314.5	320.5	329		90.5	97	100.5
9		323	321	326.5		96.0	95.5	98.5
10		320	320	327.5		94.5	98	102
11		319.5	319.5	327.5		-	-	-
Previous studies								
dos Santos (1968)	320	320	325	329				
H.P. (1969)**	323.5	323	326	329				
DNA (1980a) (maximum month)	319	316	319.5†	329				
DNA (1980a) (fixed months)	319	315	320	327				
RPT (1980)	327.5	325	328	325		100.5	97.5	100.5

* Drawing down the reservoir to the minimum operating level would still not provide adequate storage in this case.

** The results of the study by Hidrotécnica Portuguesa (1969) obtained from a later report H.P.(1973).

† This value has been amended to correct an error in the original report.

reservoir system which affect the flood rule curve and to determine the sensitivity of the system to various changes in operating parameters and procedures. The most important conclusion reached is that the system is, in fact, extremely sensitive to such changes. For example, the rule curve level on 1 February, from Calculation 1, is 326 m O.D. Allowing for possible errors in input data, on the basis of the upper 90% confidence levels in Figures 19-21 (see Calculation 2), results in a rule curve over 8 m lower on that date. The reason for this sensitivity may be clearly demonstrated using the operating procedures of Calculation 1: of the total unregulated design flood for the three most critical months (160×10^9 m^3), it is assumed that 22% is stored in reservoirs upstream of Cabora Bassa, 65% is discharged through the gates of the Cabora Bassa Dam, 8% is discharged through its turbines and only 5% is stored in the reservoir itself (requiring a drawdown level of 326 m O.D. on 1 February - 3 m below the maximum retention level). Since the discharge gates are, under these conditions, already operating at maximum capacity small changes in the estimated size of the design flood, in the upstream regulation or in the discharge capacities of the gates or turbines require large changes to be made in the flood storage provision in Lake Cabora Bassa.

A number of more specific conclusions may be drawn from these results:

1. The question of whether or not limited overtopping of the dam would be tolerable must be resolved. If overtopping is found to be unacceptable a design flood substantially greater than the 10 000 year flood must be used. It is doubtful whether the project could be adequately protected against such a flood using flood rule curve procedures, unless additional discharge capacity is provided at the dam (Calculations 3 and 4).

2. Small changes made to calculations of the magnitude of the design flood, or its inter-annual distribution, have a considerable effect on the rule curve (Calculations 2 and 5-7). In view of the difficulty of undertaking accurate frequency analysis on short data records the rule curve should, therefore, provide a suitable margin of safety. None of the previous studies made such an allowance. In particular, the rule curve proposed by RPT (1980) should be viewed with some caution because the unusual assumptions about the distribution of the design flood on which it is based resulted in a remarkably low estimate of the unregulated

March inflow*.

3. The amount of flood attenuation which is provided upstream has considerable influence over Cabora Bassa's flood rule curve (Calculation 8). It is in the interest of Mozambique to obtain a firm commitment from the operators of the Kariba and Kafue Projects to provide as much flood storage as possible and to follow consistent flood rule curve procedures.

4. The question of the maximum retention level of Lake Cabora Bassa must be resolved. The value of 329 m O.D. has been cited most frequently, but it may be necessary to adopt the lower value of 327 m if excessive upstream inundation is to be avoided (Calculation 9). Since this would entail increased flood discharges from the dam, which would result in increased downstream flooding, it would be necessary to assess the extent of both upstream and downstream flooding if the optimum benefit is to be obtained. The results obtained from simulations similar to those described below would assist in such an evaluation. The results of the SWECO (1982) study, which used a maximum retention level of 330.5 m, should be viewed with particular caution until such questions are resolved.

5. Assumptions about damage to discharge gates or the inability to operate turbines as a result of loss of load also have significant effects on the form of the flood rule curve (Calculations 10 and 11). It should be noted that these and all other effects have been tested separately on the conditions of Calculation 1. Rigorous application of UK design standards would require several of the foregoing modifications to be made simultaneously. Under such conditions the amount of flood storage required would be greatly increased and 'safe' operation of the Cabora Bassa Project would be extremely difficult without provision of extra discharge capacity at the dam.

Power Generation

Following the agreement between the Portuguese authorities and Escom on the sale of electricity to the RSA, explicit recognition was given for the first time to the fact that power generation would be the primary output from the Cabora Bassa Project. To meet the requirements

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* This feature of the RPT curve was changed in the report on their study submitted recently, Haws et al. (1982).

of the Escom contract the five generating sets, each with a nominal output of 415 MW, must operate at a load factor of approximately 78%. This requires a high level of reliability in the hydraulic and energy conversion equipment and places important constraints on the hydrological operation of the project. The purpose of the present analysis is to investigate the form of these constraints.

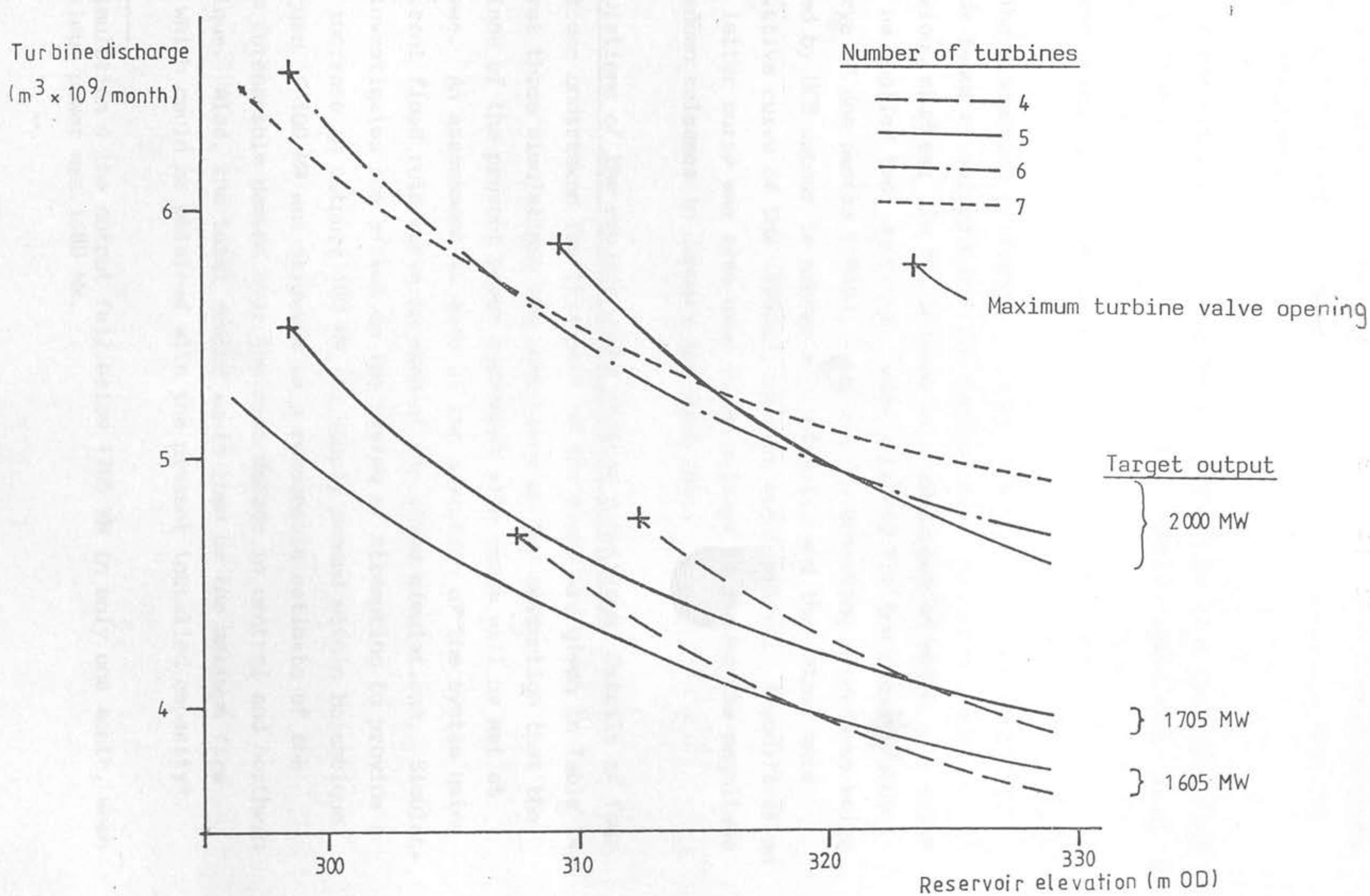
From an initial survey of the turbine characteristics, Figure 17, it is apparent that, to maintain the required output, the project must be operated in such a way that adequate values of hydraulic head are maintained. At the project's present installed capacity it is this requirement, rather than the need to store water to regulate the natural discharges of the river, which places the principal constraint on the project's operation. The constraint is made more exacting by the additional stipulation, within the terms of the Escom contract, that Cabora Bassa must be capable of increasing its output by approximately 20% of the mean value, whenever required, to meet peak load demands. Furthermore, these conditions must, at times, be fulfilled using only four of the five generating sets in order to allow repair and maintenance to take place. Thus, even from a brief study, it is apparent that any attempts by the Mozambican authorities to increase substantially the output from Cabora Bassa in order to supply their own country's demand for electrical energy will encounter serious difficulties. For this reason, attention has recently been directed to proposals to build the North Bank Station at Cabora Bassa in order to supply such domestic demand.

Arising from these general considerations two specific questions are considered by means of numerical simulations of the project's operation. First, what are the implications of operating the project according to the conditions which currently apply? The results of simulations are used in later sections of the chapter to assess how the constraints from power generation affect other potential outputs from the project. Secondly, if a North Bank Station were to be built, what would be a reasonable value to adopt as the ultimate power capacity of the project?

To assess the implications of both these questions it is desirable to simulate the reservoir's operation over a long period, rather than to select typical values for the relevant hydrological paramenters or to single out shorter periods which are believed to be critical. The need to use a long period of simulation arises from particular characteristics of the system. Under the present operating conditions, where the need to maintain high values of hydraulic head is paramount, such a simulation is necessary to assess the conflict which arises in the regulation of flood discharges. If the reservoir is held at a high level to provide high values of hydraulic head it becomes necessary to make larger flood releases from the dam which cause the level of the tailrace to rise and, thus, lead to a reduction in the available hydraulic head - this rise in tailrace level was neglected in the earliest studies of Cabora Bassa. In the evaluation of the ultimate capacity of the project a long period of simulations is required in order to assess the effect of the project's operating characteristics on power production as the reservoir approaches its minimum operating level. Excessive drawdown of the reservoir leads both to a substantial reduction in hydraulic head and to a loss of turbine efficiency. As a result, considerably more water is required to provide the same output when the reservoir is approaching its minimum level than is required at higher levels and, therefore, once the reservoir has been drawn down to such levels there is a tendency for it to remain empty. In the studies undertaken prior to 1970, three years was the longest period selected for simulation of the effects of minimum inflows. The present work indicates that this is not sufficiently long to assess such effects.

The general system characteristics used in the numerical simulations have been described earlier in the chapter - see, in particular, Figures 14-18. An alternative representation of the turbine characteristics, see Figure 24, helps to clarify some of the generating characteristics considered above. Figure 24, which is derived from Figure 17, shows the total turbine discharge required to provide a given output at different reservoir levels (assuming that the tailrace level is not increased by flood releases). The figure shows the range of reservoir levels over which a given number of generating sets can provide the required output. It also indicates the number of sets which will provide the greatest hydraulic efficiency for a given output

Figure 24: Alternative representation of generating characteristics assuming no extra spillage occurs



at different reservoir levels. High values of efficiency (the provision of a required output with the minimum turbine discharge) are important chiefly in respect of the simulations to determine the ultimate capacity of the project. However, in each of the following simulations it has been assumed, for the purposes of calculating turbine discharges, that the number of sets in operation is that which gives the greatest hydraulic efficiency.

For the simulations the reservoir inflow data used are taken from the fifty-four year series on which the RPT (1980) studies were based, see Table 13. Following the practice adopted by RPT, the simulations were conducted using equal monthly intervals each of 730 hours.

The discussion of flood rule curves, above, has indicated the wide range of values used in curves which have been proposed in previous studies. In the absense of a concensus on which rule curve should be applied two options were selected for the present study: the curve of dos Santos (1968), to which the operating procedures being followed by HCB appear to adhere most closely; and the rather more conservative curve of DNA (1980a), maximum month method. A modification of the latter curve was also used in an attempt to reduce the magnitude of drawdown releases in January and June-July.

a) Simulations of the project under present conditions: Details of four simulations undertaken for this part of the study are given in Table 14. The first three simulations are undertaken on the assumption that the conditions of the present power agreement with Escom will be met at all times. An assessment is made of the operation of the system using a different flood rule curve in each of the three simulations. Simulation 4 investigates the effect on the system of attempting to provide a modest increase in output, 100 MW, to supply demand within Mozambique. The figure of 100 MW was selected as a reasonable estimate of the maximum foreseeable demand over the next decade in central and northern Mozambique. Also, the total demand would then be the maximum firm output which could be obtained with the present installed capacity*.

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* In simulation 4 the output fell below 1705 MW in only one month, when the maximum power was 1680 MW.

Table 13 : Cabora Bassa monthly and annual inflow data as used in the numerical simulations. Source : RPT (1980)

YEAR	OCTO	NOVO	DECE	JANU	FEBR	MARC	APRI	MAY	JUNE	JULY	AUGU	SEPT	Annual total
						($m^3 \times 10^6$)							($m^3 \times 10^9$)
1924/25	2952.5	2877.0	4611.7	7481.3	26026.7	14546.9	5158.7	5040.0	4277.7	5288.5	3702.2	2933.2	84.90
1925/26	2937.7	3045.3	4862.5	15034.9	25757.6	7209.3	8867.1	6402.1	5086.1	4886.2	4253.9	3229.6	91.58
1926/27	3351.8	2839.0	3799.9	8423.4	25579.0	9766.8	14068.8	3365.3	3708.5	6447.3	3245.6	2900.2	87.51
1927/28	2942.6	2860.5	4657.9	6346.1	15855.3	9022.6	8632.0	5426.1	3149.2	3444.3	3177.9	3187.3	68.71
1928/29	3579.5	2980.9	3757.0	6489.6	13718.7	11796.3	4551.6	7227.9	3154.1	3208.4	3648.2	2931.5	67.05
1929/30	2978.9	3030.4	4230.5	7832.7	7428.6	7483.2	5143.9	2937.9	3319.1	3145.7	3318.2	2994.2	53.84
1930/31	3005.3	3141.0	4100.2	11660.7	6960.0	7108.6	8724.4	5576.3	3261.4	3726.5	3260.4	3032.2	63.56
1931/32	2922.8	3748.2	4846.0	6794.9	9389.5	11372.2	4167.1	7034.9	4178.8	4875.6	3688.9	2944.7	65.96
1932/33	3053.2	3832.3	4666.1	8494.4	22927.0	7626.7	4465.8	5510.3	3044.1	3560.8	3430.4	3240.1	73.85
1933/34	2987.2	3030.4	3438.5	7024.2	7950.0	10218.9	4749.6	4187.0	4123.1	4977.4	3324.6	2971.1	58.98
1934/35	3173.6	3091.5	7794.5	6638.1	23144.8	9223.9	6757.6	4611.0	4379.7	3623.3	3201.0	2953.0	78.57
1935/36	2939.3	2853.9	4855.9	5453.4	9156.9	12693.9	6426.0	5371.7	3076.6	4142.3	3557.1	3065.2	63.60
1936/37	3015.2	2921.5	3283.4	4933.7	20954.9	11020.8	6523.3	4272.6	4398.2	4009.2	3253.9	2872.1	71.44
1937/38	3198.4	2951.2	5060.5	6893.9	28077.8	11644.5	6418.9	3794.5	4233.6	3808.9	3785.0	2961.2	82.82
1938/39	3010.3	2910.0	4758.5	7682.6	22349.5	12852.0	7474.9	4828.7	4270.0	4166.0	4377.5	2976.1	81.66
1939/40	3173.6	2934.7	4426.9	9332.3	29928.7	11009.2	7528.7	6192.3	5394.8	4818.4	4860.1	3693.3	93.28
1940/41	3035.0	4418.1	3928.6	13962.2	26761.5	13824.2	6352.1	4251.9	4228.7	3798.2	3265.4	2972.8	90.80
1941/42	3180.2	3698.7	5481.2	6398.9	7655.0	12433.2	3584.7	2975.9	2957.8	3467.4	3224.1	2999.2	58.06
1942/43	3172.0	2947.9	3651.4	9708.8	7682.7	10933.2	4708.1	5181.0	5008.6	3997.6	3410.6	2868.8	63.27
1943/44	2987.2	2987.5	4499.5	5918.7	20490.4	16599.3	5598.2	4507.6	4373.7	4002.0	4341.4	3009.1	79.32
1944/45	3135.7	2936.4	3187.7	10342.4	14951.2	7773.6	5237.9	4799.1	6093.3	5663.2	4994.0	3609.1	72.72
1945/46	2969.0	2824.2	4801.4	6997.8	28042.1	10608.3	6154.5	3473.5	3352.4	4381.5	3272.0	2840.8	79.70
1946/47	3114.2	3020.5	6458.0	6694.2	5301.7	6960.1	4632.4	4586.3	3519.9	4763.8	4415.5	3284.5	56.71
1947/48	3318.8	3020.5	4258.6	8139.6	17869.3	11515.5	8431.0	7911.0	10625.8	6254.1	4445.0	5404.5	91.20
1948/49	3544.6	3058.5	4770.1	17739.4	20688.4	11020.8	4901.4	3815.7	3424.7	3243.0	3171.3	3042.1	82.41
1949/50	2926.1	3347.2	3380.8	4780.2	10720.3	11535.6	4239.7	4076.4	4398.6	4453.0	4077.8	3390.6	61.34
1950/51	3015.2	3327.4	3692.6	6501.2	16784.0	10880.5	4708.3	5949.2	3574.6	3942.1	4189.4	3215.3	69.78
1951/52	3018.5	2924.8	3872.5	15319.9	36079.1	16591.4	18001.2	6076.5	5117.3	5016.4	3864.8	3317.2	119.20
1952/53	3152.2	3108.0	3450.1	21921.2	32960.0	15482.4	8831.0	5787.6	5869.7	7354.4	4138.1	4170.6	116.22
1953/54	3257.8	3269.7	3728.9	22579.2	23964.6	10562.1	5372.6	4224.2	4260.9	3619.7	4022.7	2987.6	91.84
1954/55	2921.2	3172.3	3544.1	11120.7	32192.7	13674.2	4898.6	5461.3	4044.1	4635.7	4122.2	3053.6	92.82
1955/56	3086.2	2977.6	3681.1	15900.1	29358.6	15096.3	14733.7	8848.5	6186.7	8034.4	5017.9	4260.7	117.21
1956/57	3716.0	3215.2	4888.9	23806.8	29579.7	12160.7	7624.3	5836.1	4966.0	4957.6	4664.9	4006.9	109.44
1957/58	3326.4	2982.6	4189.3	18136.8	34577.3	36573.5	6856.0	5855.3	6172.3	3820.6	3064.1	2877.1	128.44
1958/59	2911.3	2842.3	4219.0	21864.7	27364.7	10471.3	3393.3	2928.0	3211.4	3119.4	3039.3	2860.6	88.21
1959/60	2903.0	2839.0	4098.5	4707.6	14169.9	9039.1	4507.0	3604.5	3132.7	3244.7	3237.3	2994.2	58.47
1960/61	2993.8	2924.8	3306.5	5758.7	20191.0	10680.9	5777.5	4081.4	4033.3	4655.1	4302.9	3582.8	72.28
1961/62	3069.7	3244.9	6329.3	23851.0	32977.7	13975.3	10135.6	6529.0	5705.2	5647.7	5133.2	4315.0	120.93
1962/63	3852.3	3293.9	6584.3	33223.3	33891.0	19896.5	12376.8	11874.6	10161.0	6993.5	5252.2	4158.7	151.54
1963/64	3504.4	3393.4	4611.7	27531.5	30419.1	7923.5	5212.4	4536.9	4058.5	3960.5	3571.9	3188.9	101.90
1964/65	3173.6	3060.1	3671.2	9223.7	17328.3	8653.0	5759.4	4093.4	3967.2	3735.8	3552.5	3256.6	69.47
1965/66	3224.8	3126.1	3790.0	4958.4	12851.4	7748.8	3901.5	3454.4	3193.1	3565.0	3227.4	2986.0	56.03
1966/67	3010.3	2933.1	3900.5	5354.4	19877.4	8766.9	6558.0	4152.3	3462.7	3541.7	3511.2	3230.2	68.29
1967/68	3214.9	3150.9	4230.5	5986.4	21921.8	8674.5	4554.9	3972.5	3497.3	3614.3	3554.1	3259.9	69.61
1968/69	3254.5	3187.2	4024.3	15452.6	26695.8	10735.3	8940.6	17471.2	10829.5	7368.9	5166.4	4190.0	117.32
1969/70	3646.5	3116.2	5731.5	30383.4	28992.9	7702.5	5686.9	5143.5	4499.0	4320.6	3766.8	3238.4	106.23
1970/71	3254.5	3233.4	7250.0	15263.9	30640.3	11292.6	6126.6	4794.5	4230.5	3783.1	3899.5	3284.6	97.03
1971/72	3256.1	3251.5	4146.4	6488.0	21592.8	7653.1	4955.8	4139.1	3543.5	3611.0	4139.8	3325.9	70.11
1972/73	3315.5	3238.3	3687.7	4512.9	5884.2	7644.9	5056.5	4135.8	3574.9	3864.3	3567.3	3253.3	51.73
1973/74	3214.9	3147.6	4390.6	7920.2	30854.8	12900.1	12088.4	5946.4	4946.0	4484.0	4145.9	3400.3	97.44
1974/75	3122.5	2976.0	4714.0	12930.7	27399.5	11592.2	7182.3	6725.9	4856.4	7827.4	3041.0	2852.3	95.22
1975/76	2891.5	2822.5	4367.5	12606.7	26481.5	15199.1	12791.5	6820.1	6382.3	5929.1	4286.3	2870.5	103.45
1976/77	3340.3	3182.2	9588.1	17931.0	30348.7	10200.7	10017.7	5285.7	3640.9	4114.0	5973.8	3361.0	106.98
1977/78	3081.2	3083.2	3628.3	12507.0	39607.8	10318.9	7306.1	17411.2	13329.0	7121.1	10246.2	4274.1	131.92

Table 14: Details of numerical simulations of the operation of the Cabora Bassa Project

Simulation	Description	Target power production (MW)	Flood rule curve (see below)	Minimum Reservoir level (m O.D.)
	PRESENT GENERATING CAPACITY			
1	Initial simulation.	1605	A	298
2	Alternative	1605	B	298
3	flood rule curves.	1605	C	298
4	Increased output from present power station.	1705	C	298
	INCREASED GENERATING CAPACITY			
5	Operation of 1750 MW North Bank Station	2600	A	298
6	at 0.57 l.f.	2600	A	308
7	Investigation of	2000	A	298
8	maximum firm power	2055	A	298
9		2082	A	298
10	output during	2110	A	298
11	critical dry period.	2137	A	298
12		2210	A	298
13	Alternative flood rule curves for simulations	2000	C	298
14	7 and 9.	2082	C	298

Description of flood rule curves

	Reservoir levels at start of month (m O.D.) Jan	Feb	Mar	Apr	Source
A	320	320	325	329	dos Santos (1968)
B	319	316	320	329	DNA (1980a)
C	316	316	320	329	Modification of DNA (1980a)

Some important results from these simulations are summarized in Tables 15, 16 and 19 and Figures 25 and 26.

From Simulations 1-4 it is apparent that the firm power output required by the Escom contract can be supplied from the present power station with little risk of shortages. Table 15 indicates, however, that some restriction is likely to arise in the peak power requirement of the contract. As may be seen from the results of Simulations 1-3 the extent of the restriction depends on the form of the flood rule curve finally adopted at Cabora Bassa. The amendment made to the DNA (1980a) rule curve (see Simulation 3) can be seen to have been beneficial in reducing the extent to which peak power output is restricted in the month of January. The additional output required in Simulation 4 almost doubles the frequency with which shortages in peak power occur.

The other important consideration in power generation is the ability to meet the required firm power output when one of the electrical generating sets is not in operation for reasons of repair or maintenance. Table 16 shows the frequency with which all five sets must be available in order to meet the required output. The influence of the flood rule curve on these results is again apparent. The increase in the firm power output in Simulation 4 is also seen to have a considerable effect.

It should be noted that, to some extent, the results of Tables 15 and 16 are determined by the assumptions on which the input data have been based and, in particular, on the assumptions made about the operating policy which will be adopted at Kariba. RPT, in preparing the data of Table 13, undertook a simulation of the Kariba Project. The operating procedures used in this simulation were relatively unfavourable to Cabora Bassa since RPT assumed that any discharges needed to achieve the annual drawdown of Lake Kariba would occur in the months of December and January. Had a more gradual drawdown been attempted there would have been an appreciable reduction in the values of inflows to Lake Cabora Bassa during these months, with corresponding reductions in the values of the data in Tables 15 and 16. Thus, the operation of the Kariba Project can be seen to have an important influence over the operation of the Cabora Bassa Project during the months of December and January when, in order to preserve an adequate hydraulic head with the

Table 15: Restrictions on peak power output during periods of flood discharge

Simulation	Required peak power - 1880 MW				Required peak power - 1960 MW				Minimum peak power (MW)	
	Number of restricted months			Restricted months as % of simulation period	Number of restricted months			Restricted months as % of simulation period		
	Jan	Feb	Total		Jan	Feb	Total		Jan	Feb
1.	2	0	2	0.3	3	0	3	0.5	1840	1970
2.	9	7	16	2.6	18	15	33	5.3	1610	1770
3.	8	7	15	2.4	11	15	26	4.2	1680	1770
4*	11	19	30	4.8	20	27	47	7.6	1680	1770

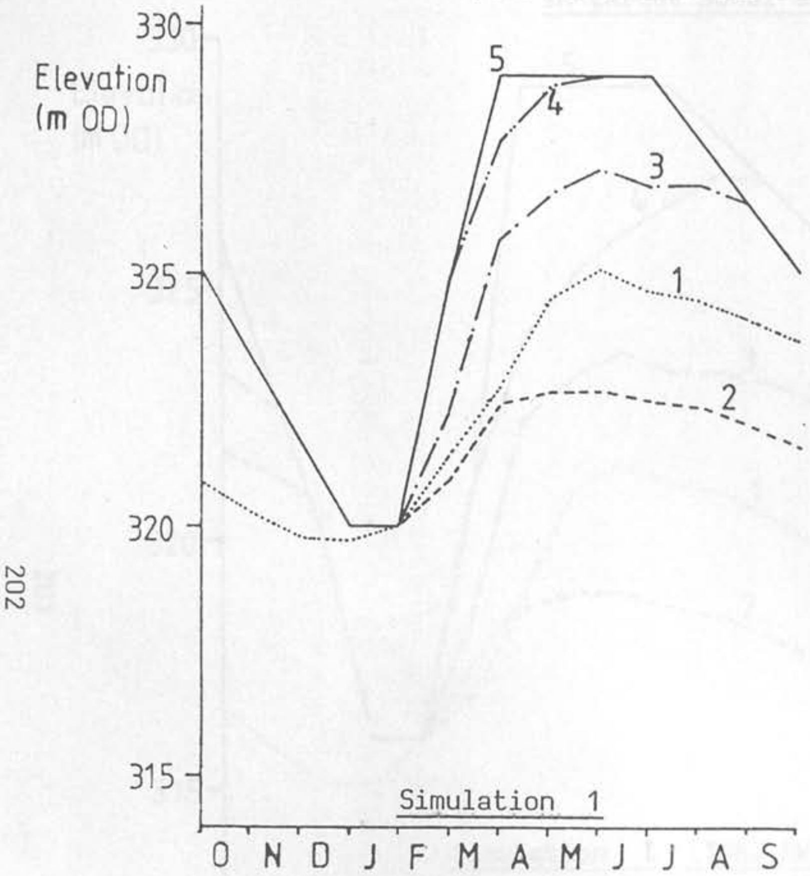
* Since the peak power required by Escom would be in addition to the 100 MW required to meet Mozambican demand, the values of peak power become 1980 MW and 2060 MW, respectively, in this case.

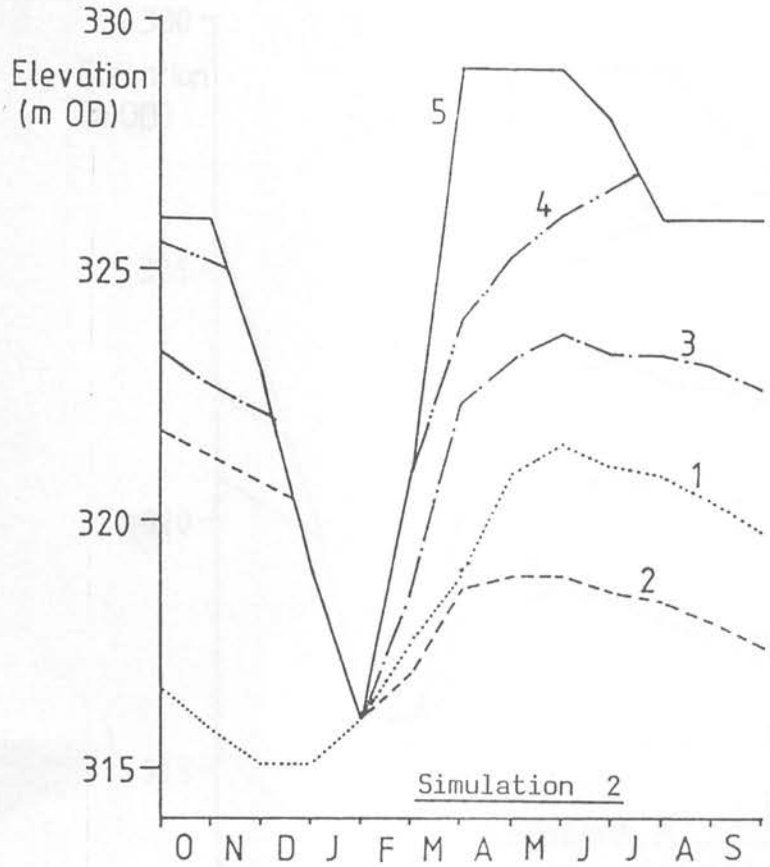
Simulation period = 54 years.

Simulation	Firm Power output (MW)	Number of years in which five sets are required in order to provide firm power throughout the given number of months				Months in which five sets are required				
		0 month	1 month	2 months	3 months	Total Number	As % of simulation period	Distribution Dec.	Jan.	Feb.
1	1605	45	9	0	0	9	1.4	0	8	1
3	1605	35	11	8	0	27	4.4	1	16	10
4	1705	13	15	6	20	87	14.1	33	28	26

Table 16: Assessment of the frequency with which all five generating sets must be used to meet target levels of firm power output with the present installed capacity

Figure 25: Selected results from reservoir simulation models showing the effect on operating levels of changes in flood rule curve - target power output = 1605 MW.





Hydrological data represented

Curve 1: 1930/1 - the year in which the lowest reservoir levels occurred (Dec. 1930).

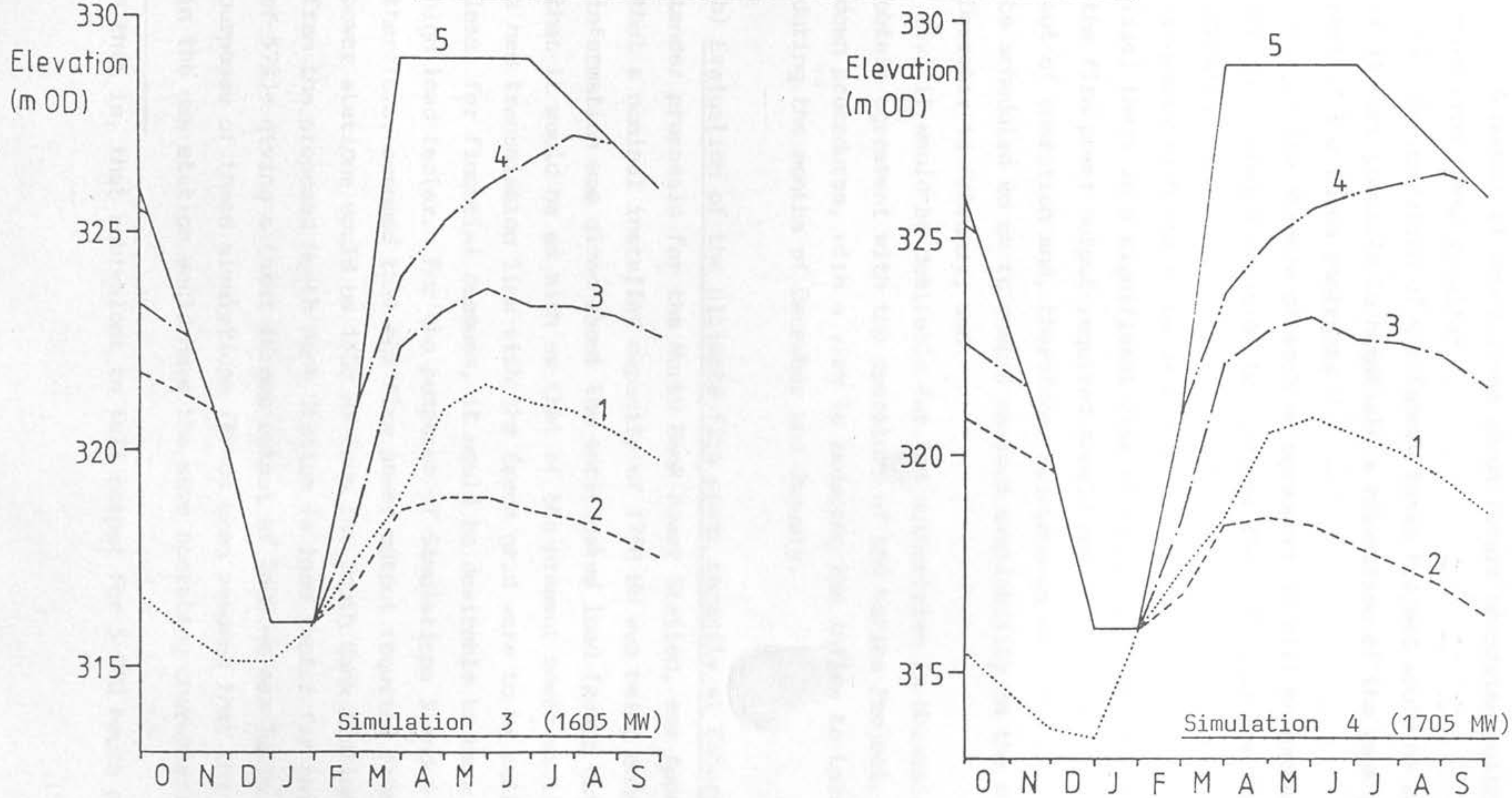
Curve 2: 1972/3 - the year with the lowest annual inflow (51.7×10^9 m^3).

Curve 3: 1935/6 - reservoir did not reach maximum operating level.

Curve 4: 1939/40 - reservoir reached maximum operating level.

Curve 5: 1957/8 and others - high inflow resulted in exact adherence to rule curve levels.

Figure 26: Selected results from reservoir simulation model showing the effect on operating levels of an increase in target power output with a given flood rule curve.



Hydrological data represented as in Figure 25 reservoir at its lowest drawdown level, flood discharges from the dam should be as small as possible.

A number of conclusions about future operating policies may be drawn from these results:

(i) the operation of the Cabora Bassa Project would be more flexible if it were possible to negotiate a relaxation of the peak power requirement of the Escom contract;

(ii) in the absence of such an agreement it will be necessary to recognize that a decision to increase the safety of the dam, by adopting a more conservative flood rule curve would increase the frequency with which the peak power requirement could not be met;

(iii) there is a significant risk of the project failing to supply even the firm power output required should one of the generating sets be out of operation and, therefore, maintenance of these machines should be scheduled so as to ensure maximum availability in the months of December to February; and

(iv) it would be desirable for the authorities in Mozambique to obtain agreement with the operators of the Kariba Project, on its drawdown procedures, with a view to reducing the inflow to Lake Cabora Bassa during the months of December and January.

b) <u>Evaluation of the ultimate firm power capacity at Cabora Bassa</u>: The tender proposals for the North Bank Power Station, see Appendix 5, indicated that a nominal installed capacity of 1750 MW was being considered. No information was given about the anticipated load factor but it is unlikely that it would be as high as that of the present power station even if a new transmission link with the Escom grid were to be built. Nevertheless, for financial reasons, it would be desirable to have a relatively high load factor. For the purposes of Simulations 5 and 6 it was, therefore, assumed that the firm power output required from the two power stations would be 1605 MW from the South Bank Station and 995 MW from the proposed North Bank Station (a load factor for this station of 57%)* giving a total target output of 2600 MW see Table 14. For the purposes of these simulations it has been assumed that the equipment in the new station would have the same operating characteristics as

* that is, that equivalent to full output for 5 000 hours per year.

that in the existing station.

Even using the most favourable of the flood rule curves, it was found that attempting to achieve this level of output would result in the reservoir reaching its minimum operating level* in about 30 of the 54 years of the simulations, see Table 17. On such occasions it was assumed, for the purpose of the simulations, that power output would be reduced to the maximum which could be generated from the inflow at the time, thus preventing the reservoir level falling below the minimum.

Simulation 6 was identical to Simulation 5 except that a higher value was used for the minimum reservoir level. The effect of this was to enable larger amounts of power to be generated in most of the years in which the minimum level was reached. It may be concluded from the results given in Table 17 that the attempt to obtain a target firm power output of 2 600 MW, under conditions similar to those in Simulations 5 and 6, would be most unwise. This is because, even with the favourable flood rule curve levels adopted, there is a mean energy deficit of between 11% and 14% and a maximum energy deficit in a single year of approximately 45%.

The results of Simulations 5 and 6 indicated that, using the input data of Table 13, the most critical period of minimum inflows covered a period of ten years from 1928/9 to 1937/8. Further simulations were undertaken, therefore, using this shorter period of data in order to determine the maximum firm power output which could be provided without deficit. For details of these, see Simulations 7-14 in Table 14. In the majority of the simulations the most favourable flood rule curve, that of dos Santos, was used but was replaced for the final two by the modified DNA curve. The results of these simulations are presented in terms of reservoir levels in Figures 27 and 28. The maximum output which could be achieved without the reservoir reaching its minimum operating level would be 2082 MW and 2000 MW, respectively,

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* In the present study, it was found to be convenient to use the figure of 298 m O.D. rather than the more usual 295 m as the minimum level in Simulation 5 but the change does not have a significant effect on the results.

Table 17: Comparison of energy deficits in Simulations 5 and 6 (Target output 22.8 TWh/yr)

	Simulation 5	Simulation 6
Minimum reservoir level (m O.D.)	298	308
Total energy deficit (TWh/yr)	167.5	129.9
Mean energy deficit (TWh/yr)	3.1	2.4
Number of years in which deficit occurred (minimum reservoir level reached)	31	30
Minimum output in a single year (TWh/yr)	12.8	13.1
Minimum output as % of target output	56	58
Longest period during which reservoir remained at minimum operating level (months)	15	13

Figure 27: Simulations 7-12 showing the effects of increased target power output on reservoir levels during the critical dry period.

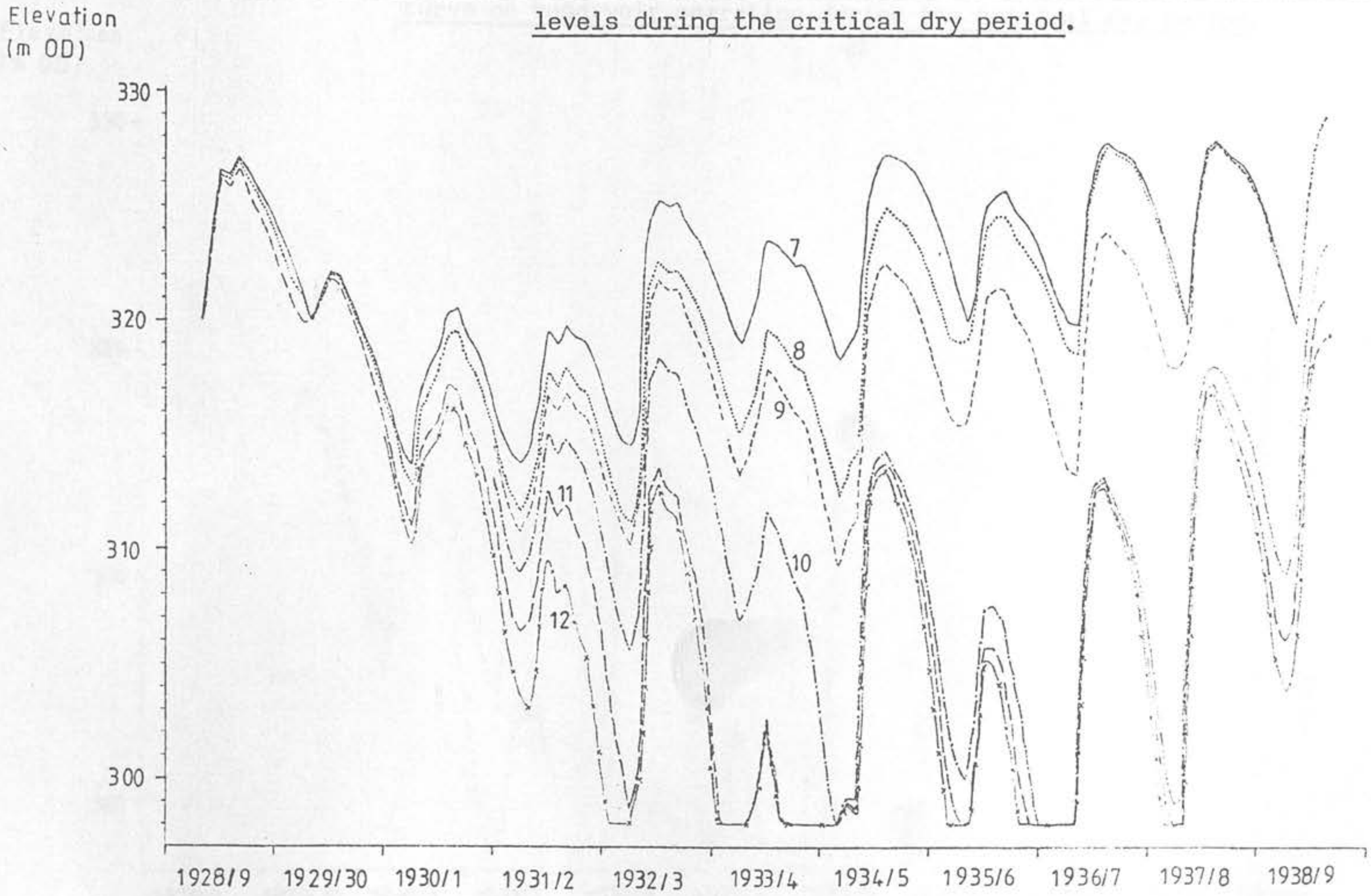
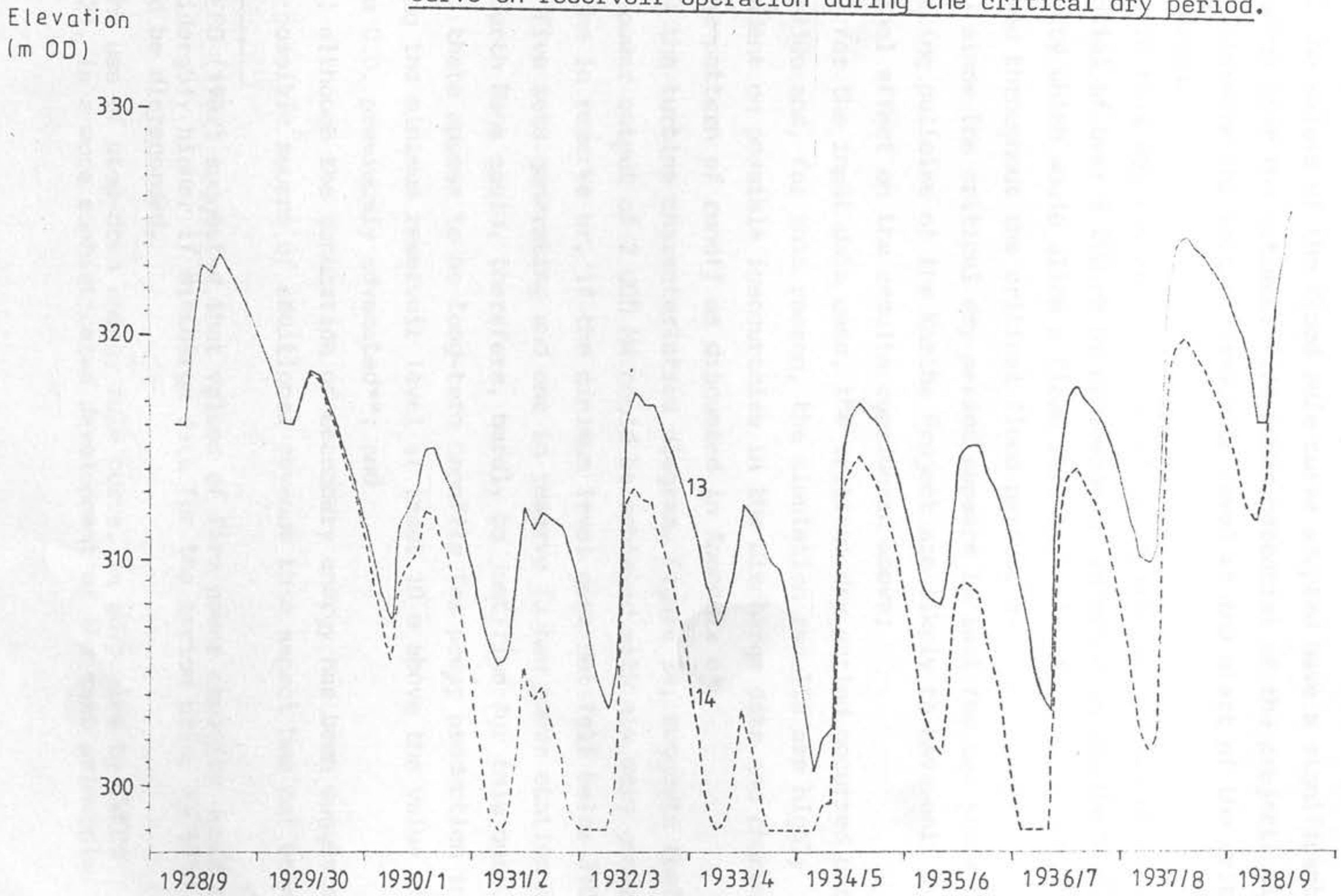


Figure 28: Simulations 13 and 14 showing the effect of adopting an alternative flood rule curve on reservoir operation during the critical dry period.



for the two flood rule curves. These values suggest that the maximum by which the present firm output of the project, as required by the Escom contract, could be increased would be no more than 25-30%.

From the results discussed above the following conclusions may be drawn in respect of proposed increases in the installed capacity at Cabora Bassa:

(i) the values of the flood rule curve adopted have a significant influence over the ultimate firm power potential of the project, since they determine the initial reservoir level at the start of the critical dry period;

(ii) in this way the SWECO (1982) study arrived at a value of firm power potential of over 2 200 MW by proposing an increase in the dam's discharge capacity which would allow a flood rule curve level of 326 m O.D. to be used throughout the critical flood period, see Figure 12;

(iii) since the critical dry period appears to last for ten years the operating policies of the Kariba Project are likely to have only a marginal effect on the results considered above;

(iv) for the input data used, the critical dry period occurred during the 1930s and, for this reason, the simulation results are highly dependent on possible inaccuracies in the discharge data and changes in the pattern of runoff as discussed in Appendix 6*;

(v) the turbine characteristics diagram, Figure 24, suggests that a firm power output of 2 000 MW could be achieved with six sets generating and one in reserve or, if the minimum level does not fall below 310 m O.D., with five sets generating and one in reserve (a new power station in the North Bank could, therefore, hardly be justified for this output);

(vi) there appear to be long-term benefits for power production in fixing the minimum reservoir level at least 10 m above the value of 295 m O.D. previously advocated**; and

(vii) although the generation of secondary energy has been suggested as a possible source of additional revenue this aspect has not been

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* SWECO (1982) suggested that values of firm power capacity would be considerably higher if discharge data for the period prior to 1950 could be disregarded.

** The use of step-down energy rule curve, as advocated by SWECO (1982), is a more sophisticated development of the same principle.

considered in the present simulations since large quantities could only be used in a large inter-connected electrical grid, such as that of the RSA (very little secondary energy could at present be consumed in Mozambique as a result of its poorly developed transmission network and lack of alternative sources of electrical energy).

Downstream flood mitigation

In the early reports of the MFPZ the flood attenuation provided by both the Kariba and the Cabora Bassa dams was grossly overstated. In the *Plano Geral* flood mitigation was listed as the second most important reason for the construction of the Cabora Bassa Project[204]. In view of such expectations the major flood which occurred in 1978 appears the more remarkable.

In early April, 1978, the engineers of HCB, aware that the major blame for the extensive flooding then occuring in the Zambezi valley might be placed on them, attempted to persuade public opinion, both in Mozambique and Portugal, that the dam had not been mismanaged. António Martins, the chief engineer in Songo, published a statement in the Mozambican press in which he claimed that the flood was an extremely rare event (with a return period in excess of one hundred years), that without the Cabora Bassa Dam the port of Beira might have been flooded and that an important factor in the downstream flooding was the large discharges from tributaries below the dam. He also attached blame to what he called:

> the deficient hydrometric network on the Zambezi which did not allow the floods to be foreseen sufficiently in advance[205].

Although it would be wrong to suppose that the operating procedures, adopted by HCB in 1978, were the major cause of the floods, this defence of the company's activities was weak. The flood was not such a rare event. Frequency analysis of one, two and three-month duration annual maximum flood series, for either the regulated inflow data of Table 13 or corresponding unregulated dishcarges, indicates that the flood had a return period of somewhere between fifteen and forty-five years. This is supported by the fact that in each of the three series for the unregulated discharges the values reached in the 1958 flood were greater.

Martins' second contention, that the port of Beira was saved by the regulation at Cabora Bassa appears far-fetched since Beira is not in the Zambezi valley. The notion has its origins in a belief within the MFPZ, and partially supported by events in 1958, that, during high floods, water from the Zambezi causes the direction of flow in the Zangoe to reverse and thereby providing a direct passage into the Púngoè basin. However, since Beira was not imperilled by the larger unregulated floods of 1958 it is unlikely that, even without the dam, the port would have been flooded in 1978.

The suggestion that large flood discharges from tributaries downstream of Cabora Bassa were partially responsible for the flooding is probably true, as it was for the floods of 1952 and 1958. Unfortunately, it is not sufficient simply to compare values of peak discharge in assessing the impact of floods; time factors must also be considered. Thus, in 1978, the dams at Kariba and Cabora Bassa undoubtedly reduced the magnitude of the peak discharge of the main river, but in so doing they delayed its occurrence in the lower valley with the result that it coincided with the tributary floods mentioned above.

Finally, Martins' criticism of the deficient hydrometric network requires careful evaluation. Certainly the operation of the Cabora Bassa Project would be greatly facilitated if the upstream hydrometric network were to be improved. On the other hand, in 1978, HCB did not appear to act upon the information received. On, or about, 9 January, CAPC[206] warned HCB that it was necessary to open discharge gates at Kariba. From 26 January three gates were opened at Kariba on successive days. Throughout this period only one gate was open at Cabora Bassa and it was not until 9 February, a month after the initial warning, that two further gates were opened. Furthermore, if HCB were to adhere strictly to rule curve operating procedures, such as those described in this chapter, there would be no need for it to rely on information from upstream.

As indicated earlier, one factor which contributed to the need for high discharges from Cabora Bassa in 1978 was the unusually high level of Lake Kariba at the start of the year - well above recommended flood rule curve levels. By contrast, the level of Lake Cabora Bassa was below the rule curve levels of dos Santos throughout the critical period. Strict adherence to this rule curve would, in fact, have allowed more of the inflow to have been stored in the reservoir and thereby reduce the downstream discharges. The effect may be seen in Table 18 in which the operating conditions during the 1978 flood are compared with those which would have occurred if the rule curves of Simulations 1-3 had been applied to the same input data. The results show that although only a small reduction in the magnitude of the discharges could have been achieved during the peak month, April, in March and June substantial reductions could have been achieved. Smaller reductions could also have been achieved in May. In this way, the duration of the flood inundation could have been reduced. Nevertheless, HCB appears to have been attempting to prevent the reservoir level from exceeding 326 m O.D. whereas in the three simulations it has been assumed that a level of 329 m would have been acceptable. The extra storage thus provided accounts for a large part of the difference between the magnitudes of the discharges.

The influence of a chosen flood rule curve on the magnitude of downstream floods has been explored in greater detail and the results are presented in Table 19. As with the study of power generation, January is seen to be the most critical month because the increasing inflows usually experienced in that month coincide with the need to preserve a large value of drawdown. The discharges in January could be reduced by adopting a policy of more gradual drawdown at Kariba, as recommended above in the study of power generation. Although a large increase in the target level of power production (Simulations 5 and 6) may be seen to bring a slight reduction in the frequency of large flood releases, it has little effect on the magnitude of the largest of these floods and is a far less significant factor than the choice of flood rule curve.

The principal conclusion to be drawn from these simulations is that the choice of flood rule curve is dominant over, and in conflict

Table 18: Comparison of the operation of the Cabora Bassa Project, in 1978, with numerical simulations using the same input data. (mean monthly discharge from the dam and reservoir levels at the start of each month)

		Jan.	Feb.	Mar.	Apr.	May	June	July
Actual operation	discharge (m^3/s)	1900	3700	10 000*	10 300*	8500	7800	6900
in 1978	level (m O.D.)	313.8	318.1	323.7	327.6	327.0	326.0	323.5
Simulation 1	discharge (m^3/s)	7200	4100	9800	9500	7300	5100	6700
	level (m O.D.)	320.0	320.0	325.0	329.0	329.0	329.0	329.0
Simulation 2	discharge (m^3/s)	7500	5500	5100	9500	7300	6100	7200
	level (m O.D.)	319.0	316.0	320.0	329.0	329.0	329.0	328.0
Simulation 3	discharge (m^3/s)	5100	5500	5100	9500	7300	5100	6100
	level (m O.D.)	316.0	316.0	320.0	329.0	329.0	329.0	329.0

* Peak mean daily flow = 14 750 m^3/s

Table 19: Assessment of the frequency with which total discharges from the Cabora Bassa Dam would exceed a mean monthly value of 7 000 m^3/s

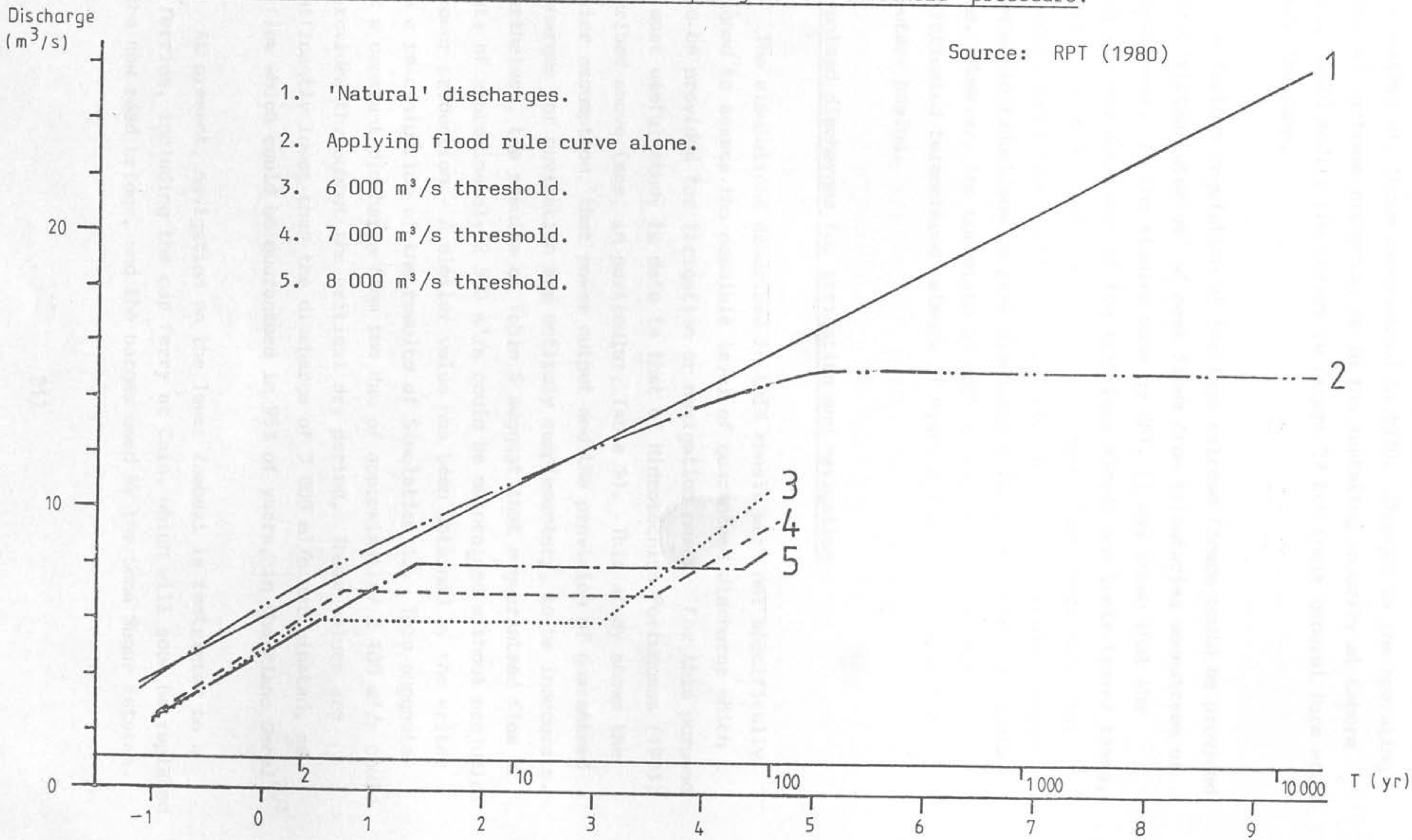
Simulation	Occasions on which limit exceeded				Maximum mean monthly flow ($m^3/s \times 10^3$)		
	January	February	March	Total	January	February	March
1	8	8	1	17	12.6	10.5	9.7
2	18	21	0	39	14.7	11.9	5.6
3 and 4	8	21	0	29	12.4	11.9	5.6
5 and 6	8	4	1	13	12.6	10.5	9.7

with, the control of flood releases downstream of the dam. The operation of the Kariba Project is also a significant factor, particularly in the month of January. The adoption of a flood rule curve which reduces the long-term risk of dam failure results in larger and more frequent flood discharges which give rise to higher levels of risk, in the short-term, to lives and property downstream. This short-term risk can, however, be reduced by adopting the policy of 'threshold' releases advocated by RPT. The results obtained from adopting such a policy are summarized in Table 6 above and are presented graphically in Figure 29.

Curve 1, in Figure 29, represents the assumed linear distribution of flood frequencies for the unregulated flows at Cabora Bassa whilst Curve 2 represents the flood frequencies after regulation at the Kariba and Cabora Bassa dams. Curve 2 demonstrates that, provided that the flood rule curve has been correctly evaluated (that is, no overtopping) there is a considerable reduction in flood magnitude for floods with return periods in the range 100-10 000 years. Curves 3-5, for which a policy of 'threshold' discharges has been used, show how further reductions in the magnitude of floods, with return periods in the range 5-500 years, may be achieved. Curves 3-5 also show the relative merits of choosing particular values for the threshold. Up to return periods of approximatley 50 years the rule appears to be 'the lower the threshold the greater the flood attenuation'. However, with these lower values the threshold is more readily exceeded. Once this has occurred the frequency curves rise steeply to meet Curve 2 at return periods in the range 500 - 1 000 years. Attempts could be made to optimize the choice of threshold by considering the relative flood damage costs but, in the absence of adequate information to undertake the necessary rigorous economic study, the safest policy would be to select the highest threshold which could be sustained without causing major flooding downstream, probably 7 000 m^3/s.

To sum up, the work of RPT has shown that floods downstream of Cabora Bassa could be further regulated without significant loss of power production, but that for the more extreme floods the flood rule curve becomes the sole determinant of the magnitude of these discharges. Thus, even if RPT's 'threshold' procedure is adopted, floods with return

Figure 29: The effect on flood frequencies of adopting RPT's 'threshold' procedure.



periods of the order of 500 years would result in discharges equal to, or in excess of, those experienced in 1978. Changes in the operating policy of upstream projects, or in the installed capacity at Cabora Bassa, would modify the curves in Figure 29 but their general form would remain the same.

A further regulation of the less extreme floods could be provided by the 'virtual storage' of peak flows from tributaries downstream of Cabora Bassa. In the studies made by RPT, it was shown that the magnitude and duration of the tributary floods and their travel times, relative to wave travel times along the main river, were such that temporary reductions in the outflow from Cabora Bassa could produce appreciable reductions in peak discharge values downstream of Lupata Gorge. However, the operation of such a system would require a sophisticated telemetered network of hydrological stations in the tributary basins.

Guaranteed discharges for irrigation and navigation

The simulations described in this thesis were not specifically designed to assess the possible level of guaranteed discharge which could be provided for irrigation or navigation needs. For this purpose the most useful study to date is that of Hidrotécnica Portuguesa (1973) described above (see, in particular, Table 5). This study shows the earlier assumption, that power output and the provision of guaranteed discharges for navigation are entirely complementary, to be inaccurate. Nevertheless, the results of Table 5 suggest that a guaranteed flow at Lupata of approximately 2 300 m³/s could be maintained without prejudice to power production. A similar value has been obtained by the writer from a re-evaluation of the results of Simulation 13. This suggests that a constant discharge from the dam of approximatley 2 100 m³/s could be provided throughout the critical dry period, These values are significantly lower than the discharge of 3 000 m³/s anticipated, as the flow which could be guaranteed in 95% of years, in the *Plano Geral*[207].

At present, navigation on the lower Zambezi is restricted to a few ferries, including the car ferry at Caia, which will soon be replaced by the new road bridge, and the barges used by the Sena Sugar Estates.

The prospects for future expansion of navigation depend partly on the minimum guaranteed flow of the river, but more significantly, on the morphological characteristics of the channel; these are examined in Chapter 5. However, even with the present low utilization of the river for navigation, the operation of the Cabora Bassa Project has created problems. For example, a public notice, published in *Notícias de Beira*, in June, 1980, apologized for the interruption to the Caia ferry which was caused by the unusually low river level.

An engineer in the DNA offered the opinion that a minimum flow of 2 000 m^3/s was needed to ensure that navigation would be possible at Marromeu. He also said that HCB had been requested to discharge at a minimum rate of 1 600 m^3/s from Cabora Bassa[208]. Table 20 shows the number of occasions, between 1976 and 1979, on which the discharge from Cabora Bassa fell below 1 600 m^3/s. Failure to maintain this discharge during the period June to December would be most harmful to navigation since tributary discharges would then be low. Separate consideration has, therefore, been given to discharges in this period.

Table 20: Minimum discharges from the Cabora Bassa Dam

YEAR	Days in which mean daily flow less than 1 600 m^3/s	Days in period June-Dec. in which mean daily flow less than 1 600 m^3/s
1976	248	131
1977	61	41
1978	30	24
1979	97	6

There appears to be no hydrological reason why a discharge of 1 600 m^3/s cannot be provided. Yet, if the suggestion referred to earlier, that discharge gates are not operated at partial settings, is correct such a discharge might, in practice, be difficult to achieve. The results of Table 20 show that the situation steadily improved between 1976 and 1979, largely as a result of increased turbine discharges. Nevertheless, deficits, which could have been avoided, continued to occur.

At present, very little water is extracted from the Zambezi for irrigation. In fact, for the foreseeable future, water is unlikely to be a limiting factor in the possible expansion of irrigated agriculture. If at some later date large irrigation projects are created in the lower Zambezi valley a conflict between irrigation and navigation demands may arise.

Flood 'freshets'

The report by SWECO (1982) suggested that, in certain years, environmental damage in the lower Zambezi might be caused by the elimination, or partial elimination, of the natural pattern of flood discharges. For this reason the report investigated the possibility of providing a 'freshet' discharge of 7 x 10^9 m^3 over a period of 10-12 days in February of each year. Simulations based on this mode of operation indicated that it might result in a 3-4% drop in energy production once the North Bank Power Station is i full operation. However, no investigation was undertaken, by SWECO, of the possible implications of such an operating procedure on the project as it now stands.

Fluctuation in reservoir level

The question of the maximum reservoir level for the Cabora Bassa Project has been considered above but other aspects of the possible fluctuations of the reservoir, such as the range of operating levels and the seasonal pattern of fluctuations, have a significant effect on lakeside agriculture, and reservoir fisheries and navigation. The extent of possible fluctuations in Lake Cabora Bassa has generally been underestimated although as early as 1961, in the *Esquema Geral*, it was suggested that the maximum drawdown might be of the order of 30 m*[209].
In 1972 the Ministry of Agriculture and Forestry, in Mozambique, became

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*Although large, this value is not unique for hydroelectric projects. Data presented by Bowden (1949) for the operation of fifteen reservoirs in the TVA system indicates that one, the Fontana, has a drawdown of this magnitude although, of the remainder, nine had values of drawdown less than 10 m and six had values less than 3 m.

concerned about the question of drawdown and requested information from the GPZ[210]. In the reply, an annual fluctuation of only 5.5 m was forecast. Similarly, Jackson (1974a), in his investigation of fisheries potential, was led to believe that the drawdown would be no more than 6 m.

The actual pattern of reservoir fluctuations experienced since the normal operating level of Lake Cabora Bassa was first reached, in April, 1976, may be seen in Figure 23. In two of the four years the drawdown exceeded 12 m. The fluctuation in 1978 was, in fact, 14 m. The resulting change in surface area of the reservoir was of the order of 1 000 km². The design of the dam allows a possible drawdown of 34 m but the likelihood of such a large fluctuation occuring will depend on the operating procedures adopted.

Operation of the project according to the procedures set out in the simulations above would reduce only slightly the magnitude of the annual fluctuations below the values experienced since 1976, see Figures 25 and 26. The most effective way to reduce the magnitude of the fluctuations would be to increase the capacity of the discharge gates of the dam as suggested by SWECO (1982), but the benefits of such a change would have to be balanced against the extra damage which would result from increased flood discharge downstream.

For lakeside agriculture, not only the magnitude but also the seasonal pattern of reservoir fluctuations will have a considerable influence over the utilization which can be made of the drawdown zone. Actual operations since 1976, shown on Figure 23, have not exhibited a consistent pattern of fluctuation; for example, in 1978, the minimum level occurred in January and the maximum in April, whereas in 1977 the minimum occurred in March and the maximum in July. The results of Simulations 1-3, shown in Figures 25 and 26, indicate that a more regular pattern could readily be achieved by adhering to the rule curve operating procedures. In particular, a fairly dependable pattern of drawdown could be achieved in the period October to January. However, the maximum level is likely to remain highly variable and thus agricultural operations in the period February to September will continue to be difficult.

CHAPTER 4

MINERAL PRODUCTION, INDUSTRIALIZATION AND THE SUPPLY OF, AND DEMAND FOR, ELECTRICAL ENERGY FROM THE LOWER ZAMBEZI

The purpose of the first part of the present chapter is to examine plans for mineral exploitation and industrialization in the lower Zambezi and, their implications as regards the supply of energy from the Cabora Bassa Project. Following a description of established mining activities in the region, and a summary of the plans for mineral exploitation put forward by the MFPZ, a short study is made of the general characteristics and effects of large-scale mining operations in underdeveloped countries. The energy requirements for mineral processing are then examined in the context of the proposals for the lower Zambezi valley. This analysis is illustrated by selected outline studies of mineral extraction and processing in a number of underdeveloped countries.

Turning to electricity supply systems, certain characteristics of the growth of such systems are identified by means of selected studies. The history of the electricity supply system in Mozambique is then traced and followed by studies of topics of particular relevance to this thesis: the growth in the demand for electrical energy in the Zambezi valley; the supply of power to Maputo; and the creation of a primary electrical transmission network to serve the central and northern regions of Mozambique.

In the remainder of the chapter consideration is given to the various alternatives facing Mozambique in respect of meeting local demand for energy in the centre and north of the country, providing power to Maputo, ensuring continued consumption of the present output of energy from the Cabora Bassa Project and deciding whether or not the project should be expanded through the construction of the North Bank Station. In order to undertake this analysis detailed consideration has also been given to the financial and contractual arrangements currently governing the operation of the Cabora Bassa Project and to the possibility of finding new markets for electrical energy in the region.

Mining activity in the lower Zambezi valley

Chapter 2 contains a description of the early history of mineral exploitation in the lower Zambezi valley and the influence which the trade in minerals, especially gold, had over Portuguese colonization of the region. The production of gold was, however, well established before the arrival of Portuguese settlers as was the extraction and smelting of iron ore. A thriving export trade of iron implements to India, based on mines in the mountains of Sofala, was recorded in the twelfth century[211]. The working of iron by the local population was still carried out in the nineteenth century when, according to Livingstone, the iron was of extremely high quality[212].

The Portuguese belief that, somewhere in the central region of Mozambique, a vast mineral wealth was awaiting discovery persisted for four centuries and was reinforced through the work of the MFPZ, albeit with reference to different minerals. The MFPZ not only envisaged the expansion of the established coal mine at Moatize but proposed the creation of mining and metallurgical industries, in the Zambezi valley, based on other minerals, such a titanomagnetites and bauxite, which had been discovered in the region. The products, which were sought as inputs for the industries of Metropolitan Portugal, demanded a cheap and abundant supply of electrical energy as well as an economical means of transportation to suitable ocean ports.

Since independence, the Mozambican authorities have continued to emphasize the mineral potential of the region. Although, initially, their plans are confined to the expansion of coal production at Moatize it is believed that, in the long-term, the minerals of the Zambezi basin will make a significant contribution towards the expansion of the national economy.

From the early 1920s to the present the most important mining activity within the Zambezi basin in Mozambique has been the extraction of coal at Moatize. The Belgium owned company began by selling coal in the area close to the mine, the Sena Sugar Estates becoming a major consumer. In 1935, when the Trans-Zambézia Railway was built from Beira to Blantyre, this company also began purchasing coal from the

Moatize mine. However, it was not until the rail link to Moatize was built, in 1950, that the widespread supply of coal in large quantities became feasible. The growth in production at the mine from 1952 to 1978 is shown by the data of Table 21. Supplementary data, not presented here[213], indicate that, in 1962, 190 x 10^3 t (approximately 63% of output) was purchased for railway use, almost three-quarters of this on the line from Beira to Salisbury. Although, as Table 21 shows, the Moatize rail link acted as a stimulus to production after 1950, output stabilized during the late 1950s and 1960s. Further expansion did not occur until about 1970 when the effects of a new and expanding Japanese export market began to be felt. Since independence there has been a considerable effort to increase output in order to earn foreign exchange from sales abroad. The Government is committed to even steeper increases in the next decade with planned output rising to 2.5 x 10^6 t by the end of 1980[214], 4 x 10^6 t by 1982 and 12 to 15 x 10^6 t by 1990[215]. Whether such outputs will be achieved will depend on many factors of which the most immediate is the inability of the present rail and road network to handle this quantity of coal.

In contrast to these ambitious plans coal has, until now, had a relatively minor influence on the economy and development of the region. In 1959 the mine employed only 1 000 workers[216] and by 1978 this number had increased to 1 500[217]. Electricity consumption at the mine has also been small, in absolute terms, although the 2.4 GWh consumed there in 1959 was over 17% of the industrial consumption of the Zambezi basin and over 90% of the total consumption of Tete Province in that year*. Nevertheless, the Moatize mine has not been a significant factor in stimulating electricity supply systems in the region. In economic terms, it was estimated that, in the late 1950s, forestry and agriculture accounted for 50% of the gross internal product of the lower Zambezi basin. By comparison, the 20 x 10^3 contos revenue from coal mining contributed only about 1½%, taking the region as a whole, or about 8%, taking the Province of Tete by itself[218].

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* Comparable figures for more recent years have not been published but, despite an increase in consumption at the mine resulting from increased output and mechanization, annual totals are now a much smaller proportion of the total consumption in Tete Province than in 1959.

Table 21: Coal production at the Moatize mine, 1952-78

Year	Total Output (t x 10³)	Exports (t x 10³)	Destination of exports	Sources
1952	140	-		1
1953	160	-		1
1954	140	-		1
1955	170	-		1
1956	220	-		1
1957	270	35(13%)	Malawi	1 and 2
1958	250	-		1
1959	260	-		1
1960	270	-		1
1961	320	-		1
1962	300	37(12%)*	Malawi	1
1965	280-300	-		3
1970	350	100(29%)	Japan, Kenya Malawi, Angola	4
1978	600	-	N. Korea, Romania Malawi, Japan	5

- indicates date not available from these sources.

* not including coal used on railways in Malawi and Rhodesia.

Sources: 1. Cabrita (1964) p88-9
2. Falcão (1963) Table XIII
3. *Plano Geral, Texto,* pI.8
4. Martins (1974) Table 9
5. Agência de Informação de Moçambique, *Information Sheet,* Maputo, 23 May 1978.

Small quantities of various high value minerals have been mined in the Zambezi basin on a commercial scale. The *Relatório Preliminar (2)* suggested that, in 1954, these included radioactive minerals and corundum from the regions around Tete, asbestos, bauxite and gold from the regions around Beira and beryl, bismuth, columbite, mica and gold from the regions around Quelimane. The list, given by Falcão (1963), for the late 1950s is substantially the same except that corundum, asbestos and bauxite were omitted and specific mention was made of samarskite* and rutile**. At that time the total annual revenue from all minerals except coal appears to have been less than 10 x 10^3 contos. In the *Plano Geral*[219] the main mining concessions listed were for coal at Moatize, radioactive minerals near Tete and copper at Chídùe. Of these only coal production was considered to be of commercial importance.

In the late 1960s, the Portuguese authorities began a campaign to attract foreign investment to Mozambique which brought companies from the RSA, Japan, Europe and the USA to search for minerals in the Zambezi valley. Although few of these companies were able to achieve even an adequate preliminary survey there was, by the end of 1971, an increase in the published figures for total mineral output from this area†. These figures should, however, be viewed with some caution since it has been revealed that at least part of this increase can be attributed to covert marketing arrangements for minerals of Rhodesian origin - arrangements devised in order to overcome United Nations economic sanctions[220].

Mineral potential of the lower Zambezi valley

Although a number of texts have been written on the geology of the lower Zambezi valley[221], it is extremely difficult, from available information, to formulate an accurate assessment of the region's true mineral potential. Pelletier (1964) has concluded that 'Mozambique is poor in mineral deposits', and in respect of radioactive mineral deposits in the Zambezi valley he wrote:

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* a uranium columbium ore.

** a titanium ore.

† the figures include, for example, 8 x 10^3 t/yr fluorite for export to Germany (F.R.), Japan and Portugal, see Martins (1974) p135-9.

> The discovery of radioactive minerals at Mavuzi about 30 miles north of Tete attracted a good deal of attention in 1948. The mineral however was davidite, a highly refractory mineral, and its occurrence was sporadic. A small quantity was sold to France. (p245)

By contrast, the MFPZ painted a picture of the Zambezi valley as an unusually rich mineralogical area[222]. Apart from those minerals already mined, deposits of the following were reported: graphite, titanomagnetite* and ores of manganese, magnesium, barium, nickel, chrome and lead. Figure 30 shows the type of map published by the MFPZ to indicate the locations of these deposits. Unfortunately, the size and quality of the deposits was not reported in detail and may not, in fact, have been known. As the intensity of Frelimo's resistance to the Portuguese regime increased it became impossible for geologists to undertake adequate field investigations. Furthermore, it was in the interests of the Portuguese authorities to allow exaggerated claims of mineral wealth to circulate in order to attract foreign companies to the region. Recently a more restrained assessment has been made in a report, by Obretenov (1978), which concluded that previous prospecting work in the whole of Mozambique:

> generally speaking ... can be considered as insufficient, non-systematic and incomplete. (2.2)

Regarding mineral deposits the report states that:

> the existing documentation ... does not permit, at this time, an evaluation of their reserves. (5.5)

Specific aspects of the MFPZ's plans are considered below.

a) <u>Coal</u>: Coal from the mine at Moatize was, at first, largely burned to raise steam. As the export trade increased so the demand for coal of coking quality grew. In the early 1960s concern was expressed that the Moatize mine might not be able to provide sufficient coal of the required quality[223]. It was at this point that interest was first shown in coal deposits in the vicinity of rio Macanha, now partially submerged

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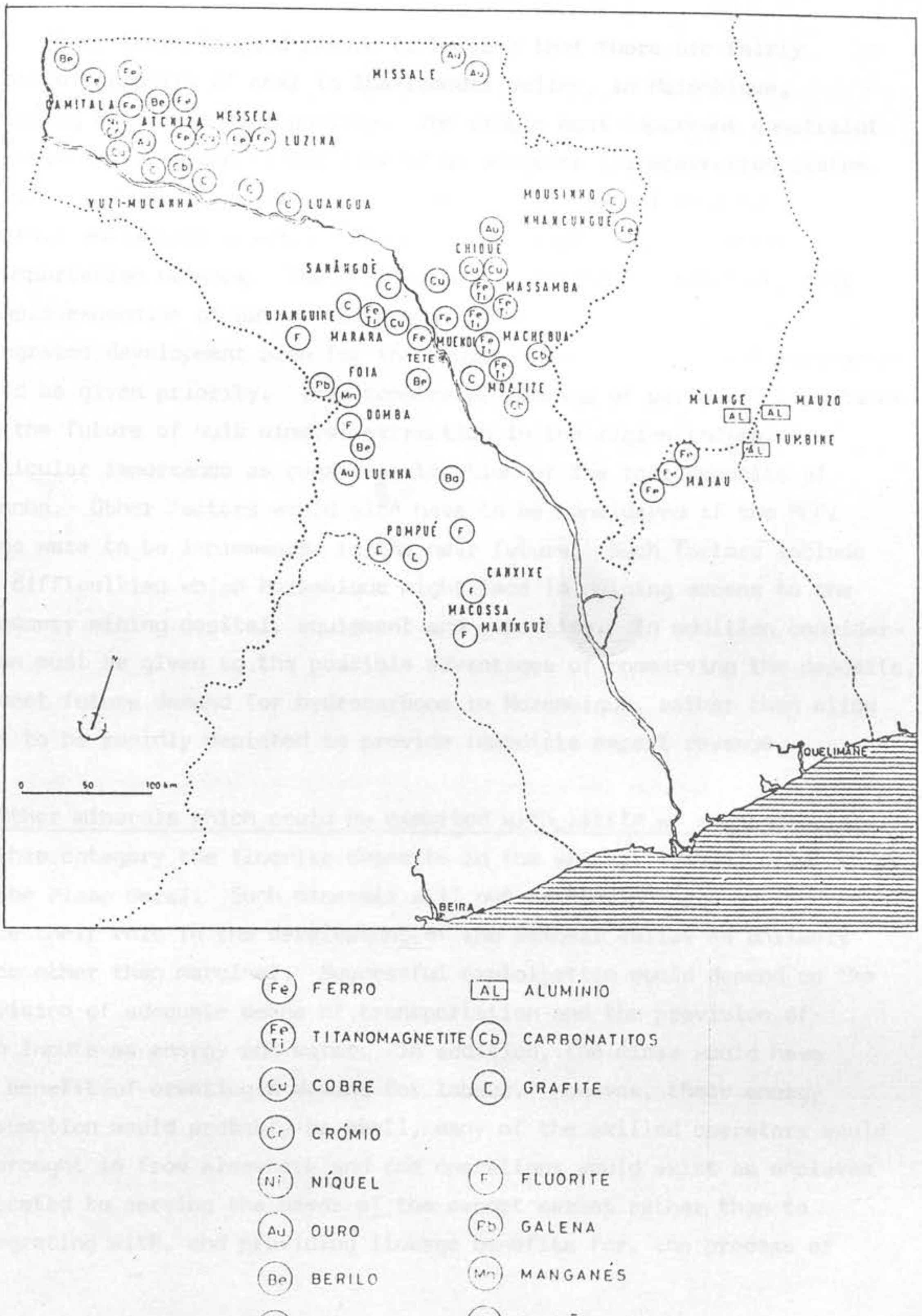
* from which iron, titanium and vanadium can be obtained.

Figure 30: Reported mineral resources of the lower Zambezi basin

Source: GPZ (1971b) p22



along the north shore of Lake Cabora Bassa. By the time of publication of the *Plano Geral*, less than five years later, these deposits had come to be regarded as one of the three 'most hopeful poles of growth in the region'[224]. Further deposits have also been located in the region including deposits on the Malawi border south-east of Moatize.

Thus, there is good reason to believe that there are fairly plentiful deposits of coal in the Zambezi valley, in Mozambique, including coal of coking quality. The single most important constraint on their exploitation is the lack of an adequate transportation system. However, the movement of coal, by itself, would be unlikely to generate sufficient revenue to justify the creation of a complete transportation network. The MFPZ planners concluded, therefore, that a rapid expansion of output could only be achieved as part of an integrated development plan for the region in which river-based transport would be given priority. This constraint remains of paramount importance for the future of bulk mineral extraction in the region and is of particular importance as regards extraction of the coal deposits of Mucânha. Other factors would also have to be considered if the MFPZ plans were to be implemented in the near future. Such factors include the difficulties which Mozambique might face in gaining access to the necessary mining capital, equipment and expertise. In addition consideration must be given to the possible advantages of conserving the deposits, to meet future demand for hydrocarbons in Mozambique, rather than allow them to be rapidly depleted to provide immediate export revenue.

b) Other minerals which could be exported with little or no processing:
In this category the fluorite deposits in the valley featured prominently in the *Plano Geral*. Such minerals will not be considered here in detail since their role in the development of the Zambezi valley is unlikely to be other than marginal. Successful exploitation would depend on the provision of adequate means of transportation and the provision of such inputs as energy and water. In addition, the mines would have the benefit of creating a demand for labour. However, their energy comsumption would probably be small, many of the skilled operators would be brought in from elsewhere and the operations would exist as enclaves dedicated to serving the needs of the export market rather than to integrating with, and providing linkage benefits for, the process of

industrial development within the region. In the Portuguese plans such characteristics had been recognized in that these operations would not have received government finance but would have to have been supported by foreign capital and operated with foreign expertise. The general characteristics of mineral exploitation by foreign companies in under-developed countries are considered below.

c) Minerals which could be processed locally: The *Plano Geral* placed much greater emphasis on minerals which could be processed locally and, in particular, those which would require large quantities of electrical energy in the smelting and refining processes. The establishment of such operations would, it was believed, provide a market for the abundant energy from Cabora Bassa, reduce the bulk of materials requiring transport to the ports, provide valuable inputs to Portuguese industry and stimulate industrial development in the Zambezi valley.

Of the suggested mineral-based energy-intensive industries the refining of the titanomagnetites of Machédua has been given greatest prominence. In the *Plano Geral* this was listed, with the coking coals, already mentioned, and the production of abundant and cheap energy, as one of the three 'hopeful poles of growth in the region'[225]. The ore consists of a mixture of magnetite and ilmenite in varying proportions. It contains, in the form of oxides, typically, 50% iron, 12% titanium and 0.3% vanadium[226]. Local smelting and refining, using low cost hydro-electric energy, was advocated not only for the reasons stated above but also because direct export of the ore could not compete, on the world market, with established sources* and because the presence of titanium in the ore would be seen, by many potential consumers, as an undersirable impurity. A smelting process, tested with co-operation from a North American firm, Strategic-Udy Process Inc., showed that coal from Moatize could be fused with the Machédua ore in a rotary furnace, without additional fluxes, and that reduction could then be continued in an electric arc furnace[227]. The principal inputs required to achieve a 500×10^3 t/yr output would be: ore, 1.2×10^6 t; coal

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* For example, the RSA claims to have iron ore reserves of 5×10^9 t at Gamagora at least 20% of which can be reached with open cast mines. The size of these reserves is twenty times greater than the iron ore reserves of the Zambezi basin reported in the *Plano Ceral* (see The Times, London, Dec. 1980).

330×10^3 t; and electrical energy 925 GWh*. Earlier proposals, in the *Esquema Geral*[228], had suggested that a plant with four times this capacity would be built, eventually, whilst Falcão (1963) believed that a 1×10^6 t/yr output could be achieved in the near future. In the event, the *Plano Geral*[229] recommended, initially, only the construction of an industrial scale trial plant.

Following the decision to proceed with the building of the Cabora Bassa Dam doubts were expressed, within the GPZ, as to whether even a modest trial plant could be operated. Ironically, the problem arose from the, apparently, rigid terms of the agreement to supply power from Cabora Bassa to Escom which, it was feared, would not allow sufficient spare power for local consumption[230]. The terms of the original agreement, as recorded at the end of 1971, would have allowed only 55 MW for consumption in Mozambique in 1975 to be increased to 100 MW by 1980 and a possible 150 MW thereafter[231]. It is not clear whether a modification of this agreement was negotiated but, by April 1972, the GPZ was talking in terms of a supply to Tete which, by 1975, would be sufficient to meet the needs of an initial steel plant with four furnaces having a power demand of 120 MW[232]. Whether the agreement was modified or not, it is clear that both parties considered it to be an interim measure which would operate only until the North Bank Power Station had been built. Indeed, initial contracts for the construction of this station had been placed before work on the dam itself had been completed. The proposal for a steel works in Tete was not, however, implemented although, in March 1974, an announcement was made that agreement had been reached with the Companhia de Urânio de Moçambique to build the first phase of the smelter, with 25×10^3 t/yr capacity by 1975, which would be linked with a rolling mill in Beira[233]. Following the coup in Lisbon, and Mozambique's transition to independence, work on the project ceased.

From published accounts it is not possible to determine the extent to which revenue from the transport of inputs and products for the proposed steel industry would have helped to finance the transportation network which would be necessary for its success. Nor has it been

* Equivalent to a power demand of 130 MW at the projected load factor of 0.82 (7180 hours operation per year).

disclosed whether the electrical energy would have been charged at the same rates as those which apply to sales to Escom. Nevertheless, in the long-term, it was believed that economic benefits could be achieved through the refining of the two ore 'impurities', titanium and vanadium. Both are difficult and costly to refine and require large inputs of energy. Titanium sponge can be produced by electro-refining with each tonne of product requiring about 30 - 40 MWh, twice the energy requirement for smelting a tonne of aluminium. The general characteristics of these and other energy-intensive processes are considered in more detail below.

Mineral exploitation in underdeveloped countries

In view of the emphasis placed on mineral exploitation in the Portuguese plans for the development of the Zambezi, it is worth considering the general characteristics of such operations in underdeveloped countries or regions. The principal source on which these observations are based is a report prepared for the World Bank by Bosson and Varon (1977). Other studies to which reference has been made include Warren (1973), who provides a general description of the characteristics of the mining industry throughout the world including brief discussions of its impact in underdeveloped countries; Cobbe (1979), who examines the relationship between mining companies and the governments of underdeveloped countries based on case studies from various parts of the world; and Lanning and Mueller (1979), who concentrated on the effects of mineral exploitation in Africa. Whereas the majority of published studies are based on the premise that mineral exploitation, in the long-term, can bring benefits to both the producer and the host country, Lanning and Mueller consider such an assessment to be too sanguine in view of the many instances, which they document, of the heavy costs paid by African countries in exchange for mining technology and export markets.

The work of Bosson and Varon draws attention to the unequal nature of the relationship which is involved when technologically advanced countries become involved in the exploitation of mineral resources in an underdeveloped country, particularly when this occurs through the agency of a large multinational company. Underdeveloped countries encourage the mining companies in the expectation that they will bring the following benefits:

(i) foreign exchange earnings;
(ii) income from taxes and royalties;
(iii) stimulation of the economy of depressed regions;
(iv) introduction of new professional and technical skills; and
(v) the possible formation of a nucleus for national economic growth.

In many cases, such expectations are, at best, only partially fulfilled whilst, on the other hand, mineral exploitation may produce significant effects associated with the following features:

(i) mining enterprises tend to remain as enclaves which are not integrated with the economy of the host country;
(ii) they frequently show little concern for possible environmental damage; and
(iii) the industry shows a highly skewed income distribution.

The case of iron ore extraction in Liberia provides an extreme example of a mining enterprise which is totally detached from the national economy and which has failed to stimulate local industrial activity. The railways, which were built twenty years ago for the benefit of the mines, lead straight to specially constructed deep-water ports and are of little benefit to the rest of the Liberian economy. No local steel industry has been created and all the inputs required for the mines, apart from a little fresh food, are imported. Lanning and Mueller conclude that, after twenty years, 'Liberia ... is as far from industrialization as ever'[234].

Two characteristics of large-scale mining and mineral processing activities are particularly responsible for the social, economic and environmental dangers outlined above; firstly, they have become very capital intensive and, secondly, they carry a large element of risk.

Throughout the twentieth century the capital input to the extraction of minerals has contributed an increasing proportion to production costs. Part of this has resulted from a deliberate policy on the part of producers to displace labour although other factors, such as the desire to achieve 'economies of scale' and the need to use lower grade ores, have been significant. Since underdeveloped countries lack capital and technological resources, whilst being rich in labour, such a trend has made the minerals industry progressively more inaccessible to them except on the most disadvantaged terms.

The high levels of risk arise from geological unknowns, changes in economic or commercial factors and political uncertainties. The risks are increased by the long periods of project evaluation and implementation which are required to obtain output from previously unexploited reserves.

Against this background it can be seen readily that the objectives of industrially advanced countries and of underdeveloped countries are often in direct conflict. The industrialized countries are concerned to secure cheap and dependable supplies of raw materials. On the other hand, individual underdeveloped countries are seeking to increase their national income, influence the geographical pattern of development in their country, encourage backward and forward linkage effects in the economy, including an increase in industrial output, and limit adverse environmental consequences. Policies which reduce the risks and costs to the technologically advanced party inevitably involve each of its less developed trading partners in a disproportionately high share of the risks and costs. This is particularly true if the less developed countries remain as competitors with each other.

From the foregoing discussion a number of conclusions may be drawn which would be relevant to any future attempt to expand mineral production in the Zambezi valley:

(i) an improved and expanded transportation network would be essential for large-scale mineral production but, unless care were taken in its planning, such a system might not adequately serve other transport needs in the region;

(ii) even where the existence of rich and plentiful reserves has been proved, which is not the case at present in the Zambezi valley, it is by no means certain that a country such as Mozambique could achieve substantial economic benefits from their exploitation because of the unequal nature of the relationship between that country and the

technologically advanced country or company from which the necessary capital and expertise must be obtained;
(iii) as a result of this unequal relationship it is also unlikely that a country such as Mozambique could achieve its social, political and industrial objectives or exercise the control it would like over such matters as environmental protection and regional planning; and
(iv) heavy reliance on the export of a small number of raw materials to markets over which the exporting country can exert little influence is likely to produce an unbalanced and potentially unstable national economy.

Energy-intensive processes

In much of what has been written, over the last two decades, on mineral production and industrialization in underdeveloped countries it has been suggested that the exploitation of large-scale hydroelectric sources close to rich mineral deposits offers an attractive route to economic development through the establishment of energy-intensive industries. Suitable sites for such projects have been proposed in various parts of Africa[235]. One of the minerals which has attracted interest in this respect has been copper. Prain (1975) suggested that:

> The ultimate constraint in the future production of copper is ... the availability and cost of future supplies of energy. (p275)

However, the large scale smelting of aluminium from alumina has become the most celebrated of the energy-intensive processes which has been considered for establishment in underdeveloped countries. Smith (1975), who worked with the Kaiser Corporation of the USA on the studies for the Volta River Project in Ghana, identified the Cabora Bassa Project as one which, in his opinion, would almost certainly become linked to an aluminium smelter, in view of its low electricity generating costs. Clearly, projects of this nature are of benefit to the main consumers of aluminium products in so far as they help to maintain a low market price for the metal. It has also been argued, for example by Wilson (1975), that producing countries benefit because, after smelting, the value of the product is considerably higher than that of raw or semiprocessed alumina. Both copper and aluminium were listed in the *Plano Geral* as being found in ore bodies in the Zambezi valley and, therefore, offering the basis for energy-intensive industries using power from Cabora Bassa. Before considering these proposals in more detail the general characteristics of high energy processes will be examined. The study by Schramm (1969) of these characteristics, in relation to low cost hydroelectricity in Canada, provides a useful, if somewhat dated, basis for this discussion.

In Table 22, drawn largely from Schramm's work, the inputs of electrical energy required to give one tonne of product in various processes are compared*. The table also indicated the relative values of the outputs and the total output of each product in the USA in 1961. It is clear, from these figures, that, for an energy-intensive industry to gain in importance, not only must the product require a large input of energy per unit output but also the total annual demand for that product must be large. Thus, titanium, magnesium, phosphorus and zinc are all unlikely to provide the basis for a new large-scale industrial development because the annual demand for them is relatively small, whereas aluminium production appears to be attractive because the demand is high. Furthermore, because of the wide variations in the values of the products, those requiring the largest energy inputs are not necessarily the ones which show the greatest sensitivity to changes in the price of electrical energy. This may be seen by reference to Figure 31 which shows total costs as a percentage of product value for different energy rates. Finally, Schramm sought to identify other economic factors which might influence the location of processing industries. His conclusions, which are also included in Table 22, indicate that for all the processes considered, except the smelting of aluminium, closeness to a source of cheap electrical energy, although important, is not the dominant economic factor in project location. Even with aluminium smelters, the location of bauxite deposits and the provision of cheap transport, to supply alumina to the smelter, have a significant influence over their location. On all these counts,

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* These figures are only approximate since, in some cases, improvements in the processes have enabled energy inputs to be reduced since the writing of Schramm's paper.

Table 22: Electrical energy requirements of selected high energy processes

Product	Electrical energy per tonne output (MWh)	Value of output c.1965 (Can. $/t)	Proudction USA, 1961 (t x 10^3/yr)	Estimated annual growth of output (%)	Total consumption electrical energy for USA output, 1961 (GWh)	Dominant economic factors for location of industry
Titanium sponge	30	2 700	8.9*	10.25	27*	Input, chlorine and magnesium. Thus, indirectly transport & energy.
Ferro-alloys						
Ferro-nickel 55%	24	815				Normally produced in small plants in established industrial areas, some as by-products of other processes.
Silicon metal	13	305				
Ferro-silicon 75%	10	305	1 690	1.75	17 000	
Ferro-silicon 50%	6	276				
Silico-manganese	3.5	185				
Ferro-manganese	3	167				
Magnesium (Electrolytic)	19	733	41.3	8.75	780	Sources of clean seawater and cheap salt.
Aluminium	15	482	4 260	6-7	64 000	Cheap energy. Also source of alumina.

Table 22 continued

Product	Electrical energy per tonne output (MWh)	Value of output c.1965 (Can. $/t)	Production USA, 1961 (t x 10^3/yr)	Estimated annual growth of output (%)	Total consumption electrical energy for USA output, 1961 (GWh)	Dominant economic factors for location of industry
Elemental phosphorus	13	350	392	4.75	5 100	Location of phosphorus rock deposits.
Manganese**	8-9	-	-	-	-	--
Zinc (electrolytic)	3.5	328	215	4.25	750	Source of ore.
Chlorine and caustic soda	1.5	60	8 620	4.5	13 000	Transport costs of products (which require special handling)
Chemical pulp	1.0	-	-	-	-	Transport costs of inputs.

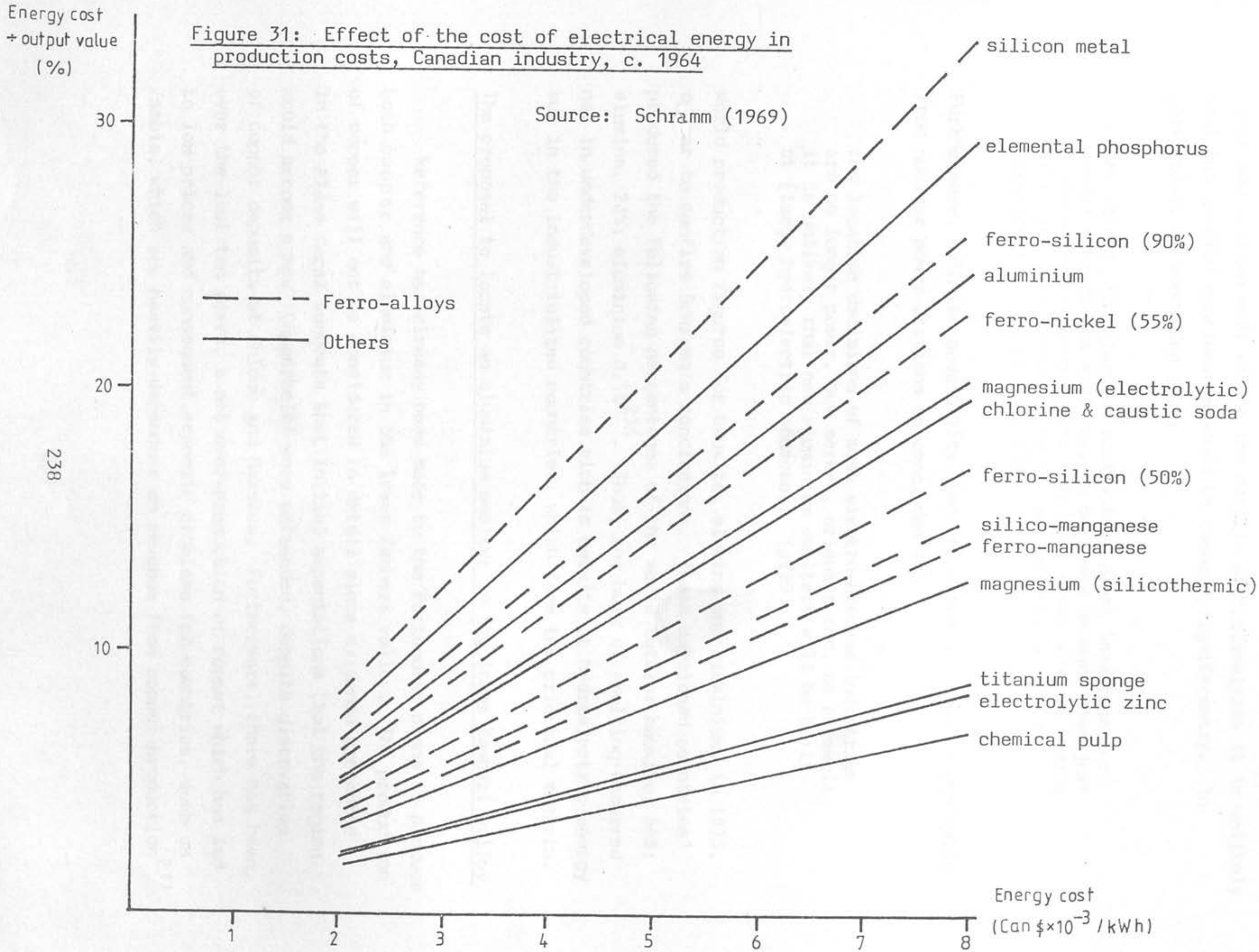
Notes: Principal source Schramm (1969)

* This figure includes the total output from 'Western' countries.

** This value is obtained from Encyclopedia of Chemical Technology, Wiley, New York, 3rd Edition (1981), 14, p836

Figure 31: Effect of the cost of electrical energy in production costs, Canadian industry, c. 1964

Source: Schramm (1969)



therefore, it is apparent why the smelting of aluminium has taken precedence over other energy-intensive processes in countries where abundant hydroelectricity is available. Although changes in the price of electrical energy and in the value of the products since Schramm's paper was written will affect the details of his analysis it is unlikely that his general conclusions would be changed significantly. In particular, he concluded that:

> Any attempt to determine most likely plant locations for specific processes will have to be based on more than just a comparison of power costs. In most cases a whole series of factors will mutually determine the best potential location for a plant. (p219)

Furthermore, with the possibility that cheap energy would be available from nuclear power stations he concluded that:

> the location decisions of most electro-process industries are no longer power, but market, oriented and, as a result, it is unlikely that new aluminium smelters will be built at [large hydroelectric sources]. (p229)

World production figures for bauxite, alumina and aluminium, in 1975, appear to confirm Schramm's conclusions. 'Less developed countries' produced the following percentages of the world totals: bauxite, 54%; alumina, 23%; aluminium 8.5%[236]. Thus, the bulk of smelting occurred not in underdeveloped countries rich in bauxite or hydroelectric energy but in the industrialized countries, which form the principal markets.

The proposal to locate an aluminium smelter in the lower Zambezi valley

Reference has already been made to the Portuguese plans to produce both copper and aluminium in the lower Zambezi valley. The production of copper will not be considered in detail since evidence presented in the *Plano Geral* suggests that initial expectations that the region would become a new 'Copperbelt' were unfounded, despite discoveries of copper deposits at Chídùe and Messeca. Furthermore, there has been, over the last ten years, a net over-production of copper which has led to low prices and consequent economic problems for countries, such as Zambia, which are heavily dependent on revenue from copper production[237].

The production of aluminium was considered in far greater detail by the MFPZ. In the *Esquema Geral* a plant with 30×10^3 - 100×10^3 t/yr capacity, located near Milange on the Malawi border, was envisaged. Alternative sources of bauxite were discussed, including small deposits within Mozambique in the same vicinity, or possible imports from larger deposits in Malawi. Some reservations were expressed but these were played down:

> Although a tendency to reach a 'boom' in aluminium production has presently been observed in the market, interest has not been lost [in this project]. About 60×10^6 t of bauxite are known to exist although the aluminium content is relatively low and the percentage of silica high[238].

The deposits referred to are presumably those in Malawi. The Portuguese authorities had taken shares in the Aluminium Corporation of Malawi with the intention, initially, of co-operating in a refinery and smelter project on the Shire River using power from Cabora Bassa. When the Malawi Government withdrew support, because it recognized the uncertain economic returns from such a project, the Portuguese planners examined the possibility of locating a smelter on the banks of the lower Zambezi and of bringing in the bauxite from Malawi[239]. During these studies it was revealed that the reserves were probably only half the size of those which had previously been reported. In the financial study for this project, which was completed in 1972, it was suggested that bauxite from deposits in Manica Province could possibly replace the Malawian bauxite after a number of years[240].

Without access to the details of the 1972 study it is only possible to speculate on its recommendations. The size of smelter used in the majority of modern plants has an output of at least 100×10^3 t/yr. Assuming a unit energy consumption of about 18 MWh/t, the electrical power demand of such a smelter would be of the order of 200 MW[241]. Smith (1975) suggested that, provided energy rates were below US $ 0.005/kWh, a smelter located almost anywhere in Africa would have been feasible. Such a generalization is undoubtedly unwise in view of the economic importance of the location of bauxite deposits and the cost of transporting the smelter's inputs and outputs. Nevertheless, from the rates subsequently incorporated in the agreement to supply power to Escom, it is probable that the energy costs from Cabora Bassa were considered to be appreciably less than Smith's figure. It is, therefore, reasonable to suppose that the report supported the conclusion that such a project would be feasible provided that an adequate and cheap transport system could be developed.

How far the present authorities in Mozambique have considered implementing the MFPZ proposals is unknown. However, the production of aluminium is listed as one of the *grandes projects* selected for priority study when the State Central Plan for 1981 was discussed at the 7th Session of the Peoples' Assembly [242]. If a smelter of the size described above is under consideration its output would be far in excess of the current demand for aluminium products in Mozambique and must, therefore, be intended, almost entirely, as a source of export earnings. Similar projects have been built in other less developed countries for this purpose. A brief description of one of these, incorporated in the Volta River Project in Ghana, will illustrate some of the problems which may arise in the implementation of such a project. The following account is based largely on the study of the Volta River Project undertaken by Hart (1980).

Construction of a 200 x 10^3 t/yr aluminium smelter at Tema, on the coast of Ghana close to Accra, was begun in 1964. The smelter, built and operated by Valco*, entered production in 1967 and draws its power from the Akosombo Dam - the principal element in the Volta River Project. This building of the dam could not have been justified at that time, without the smelter taking the bulk of its power output. The terms of the original agreement, between Valco and the Ghanaian Government, reflected the weak position of the Ghanaian State relative to the aluminium company. Ghana was required to provide generous long-term tax exemptions and concessions, and to sell the electrical energy at a price which, Hart suggests, was slightly below the cost of production. Furthermore, the Ghanaian request to the company to build a plant to refine the local bauxite into alumina, in order that an integrated aluminium industry could be created, was rejected by Valco. As a result,

* Volta Aluminium Co. Ltd. which is owned by two major aluminium companies - Kaiser Aluminium and Chemical Corporation (90%) and Reynolds Metals (10%).

the Ghanaian bauxite continues to be exported to Britain for refining while the alumina needed for the Tema smelter is imported from Jamaica.

Presumably, the Government made concessions to Valco in the belief that the smelter and dam would bring other substantial benefits to Ghana's economy. Hart's study shows, however, that in ten years of the project's operation few, if any, of the initial expectations have been realized: there has been no appreciable change in the range of the country's export commodities; foreign exchange earnings from aluminium production have been offset, largely, by the import of alumina and of other inputs needed for the operation of the smelter; and the generation of new employment opportunities has been negligible*. Even in the wider economy, where it was hoped that the Volta power would stimulate industrial growth, Hart found little evidence that the Government's expectations had been fulfilled: backward linkage effects had been minimal; electrical power to other industries was not cheap because new transmission networks had to be built and because the smelter was buying its power below cost; and the electricity and water supply systems built for the smelter reinforced the existing regional concentration of industry rather than helping to distribute industrial centres as the Government had hoped. Nevertheless, Hart found no evidence of a deliberate desire to exploit the people of Ghana nor of 'mistakes' or corruption amongst the officials who had formulated the policies and implemented the project. He concluded, therefore, that:

> the failure of the Volta River Project, as far as Ghana is concerned, must be attributed, not to ignorance, but to the basic clash of conflicting interests. (p104)

The Ghanaian experience is not unique, Guyana has paid heavily for its decision to build a 150 x 10^3 t/yr smelter[243]. In this case the cost of the project and its associated hydroelectric station was so large relative to the national budget that the project had to be abandoned when the country ran into financial difficulties in 1978.

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* 2 000 jobs were created at the smelter and a further 5 000 in the electricity corporation but the investment per workplace, amounting to about US $ 75 000, would have been considered high even in a highly developed economy.

Attempts to restore the national economy, and proceed with the project, have resulted in the imposition of external controls, by the IMF, which are at variance with the domestic policies of the country's socialist government.

More generally, the international aluminium companies have achieved a world-wide fragmentation of the industry which reinforces their already strong position. Of fourteen underdeveloped countries which Hart lists as having aluminium smelters only four produce bauxite[244]. Thus, the major companies control the supply of alumina, the supply of equipment and technical expertise necessary to smelt the alumina and the market for the aluminium produced. Recently Venezuela has encountered strong resistance to its attempt to break free of this control[245].

Presumably Mozambique, if it proceeds with a Zambezi smelter project, will have the option of obtaining the necessary equipment from the eastern European countries or the USSR. Nevertheless, it is by no means certain that Mozambique could, in that way, avoid the difficulties which other countries have experienced: the capital investment required would still be large relative to the national budget; the country would still be totally dependent on imported technology and expertise and on the import of some, if not all, of the inputs to the smelter; the aluminium produced would still be sold in a market over which Mozambique would have little influence; and, to improve the viability of the project, it would still, presumably, be necessary to provide tax concessions and preferential power rates. If the other benefits resulting from the project turned out to be no more substantial than those which resulted from Ghana's smelter, such an arrangement would have done little to stimulate the development of Mozambique's economy, as a whole, or that of the Zambezi valley.

The material in this chapter has so far been directed towards an assessment of various proposals for mineral extraction and refining in the Zambezi valley. Although these proposals formed an important part of the integrated development plan for the Zambezi valley, as devised by the MFPZ, very little had been achieved towards their implementation at the time of independence. The failure to attempt to implement the proposals is due, in part, to the absence of an electrical power network and an adequate means of transport. Nevertheless, it remains uncertain that adequate geological surveys and economic feasibility studies had been undertaken in respect of many of the proposals.

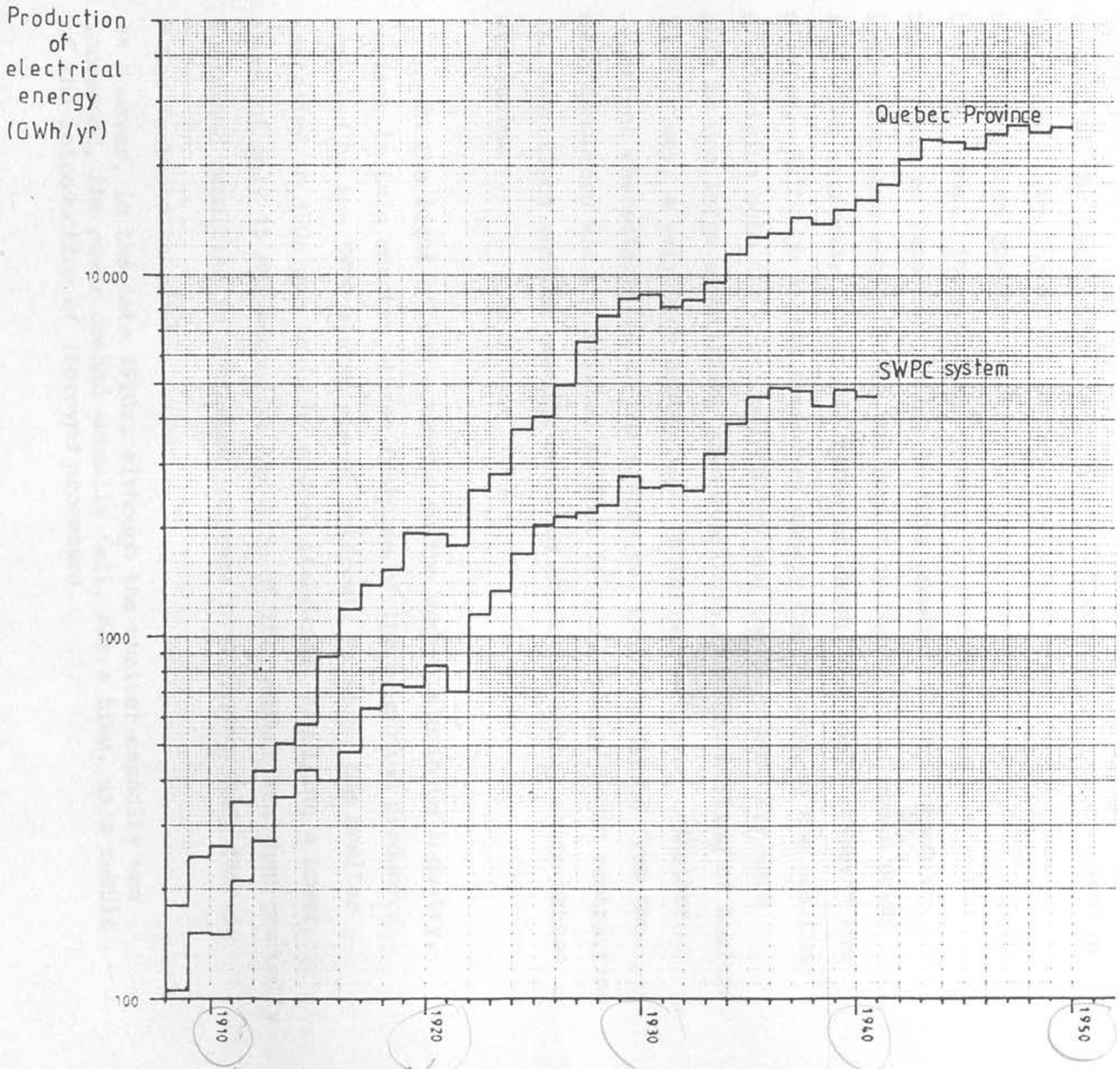
If the present authorities in Mozambique are seriously considering the exploitation of the mineral resources in the Zambezi valley they have only poor foundations on which to build, particularly as no pilot projects have been built to test the refining processes and train the necessary personnel. In addition, the Portuguese proposals were not specifically designed to benefit the economy of Mozambique but to meet the needs of the economy of Metropolitan Portugal. As indicated above, the implementation of similar projects in other underdeveloped countries has frequently led to adverse economic, social, political and environmental consequences which were not foreseen at the time of the project's inception. In order to ensure that the long-term interests of the people and economy of Mozambique are well served, a realistic assessment of such adverse effects must be made so that they may be balanced against the expected benefits which a particular project would bring.

One of the principal benefits which has been canvassed has been the stimulus which mineral processing would provide to the development of the electrical power system in the surrounding region and, thereby, to the growth of manufacturing industry. The study of the Volta River Project has shown, however, that expectations in this direction may previously have been exaggerated. The remainder of this chapter is devoted to a study of the factors which influence the growth of electrical power systems and the conclusions which may be drawn therefrom regarding the future development and operation of the Cabora Bassa Project.

Case studies in the growth of electrical power systems

Before undertaking a study of the growth of the electrical power system in Mozambique, the characteristics of three selected systems will be considered with a view to formulating some general propositions about the growth of such system. All three derive a large proportion of their supply from large hydroelectric projects. The systems operating in Quebec, selected for the first study, are now incorporated within a large highly developed inter-connected network; however, the present discussion will concentrate on their initial period of formation. The other two systems studied, in Uganda and Ghana, are still at a relatively underdeveloped stage and were, during the 1960s, of comparable size to that of Mozambique. Statistics for the production and consumption of electrical energy from these case studies are presented in Figures 32 and 33. The use of log-linear axes in these figures would result in constant gradient curves if consumption grew exponentially, as is usually assumed in forecasting future demand. The fact that constant gradients can be found only over relatively short periods, in any of the curves, indicates the limitations of such an assumption.

a) Quebec Province in Canada: This case study has been selected because of the high proportion of electrical energy which was, until recently, supplied by large hydroelectric projects and because of the importance of energy-intensive industry attracted to the region. Much of the material is derived from the detailed and informative study of Dales (1957). Figure 32 shows total electrical energy production for the Province of Quebec as well as that of one constituent system, the Shawinigan Water and Power Comapny (SWPC), from 1908 until the 1940s. The curves show that the average annual growth in output in Quebec, which was just under 25% for the first twenty years, has gradually fallen and that two World Wars and the economic depression of the 1930s had an appreciable effect on production. The phenomenal growth in consumption of electrical energy up to the 1920s was associated with a rapid expansion in export-orientated industries, such as those producing aluminium and base metals, wood pulp and calcium carbide all of which require high inputs of energy. In addition, energy was exported directly to the neighbouring province, Ontario. The proximity of the large markets of the USA and strong established trading links with Europe, boosted by wartime demand, have been important factors in securing a relatively high rate of growth of output even in the period after 1930. Over the period in question, however, Quebec



turn thro' 90°

Figure 32: Production of electrical energy in Quebec 1908-49.

Source: Dales (1957)

changed from an underdeveloped area, providing primary products for export, to a broader-based economy in which manufacturing and light industries, supplying domestic consumption, became established. Dales examined how far the availability of cheap hydroelectricity was a significant factor in this process of industrialization and concluded that other factors, including the ability to produce the bulk of the food necessary to support its population, were more important.

The separate study of the SWPC is of particular interest since this power system was established in a totally undeveloped part of Quebec, with all generation initially being from a single site, the Shawinigan Falls. Also, the system supplied energy-intensive industries, in each of the categories listed above, as well as exporting power to Montreal. Like the output of the province as a whole, the load on the SWPC system grew erratically but at a remarkably fast rate until the late 1930s. The positive approach to marketing adopted by the company was an important factor in this growth. Energy-intensive industries were attracted to the region by the offer of cheap power including extremely favourable rates at which 'secondary energy'* was offered. Although little secondary energy can be used in the smelting of aluminium both the carbide industry and the pulp industry were able to use large quantities, when available, for the heating of boilers. In this way, a very high system load factor was achieved. Another important characteristic of the system was that the demand from the main consumers was not related so that if one industry began contracting its operations another usually absorbed the extra energy which became available.

In the light of the comments on the modern aluminium industry, earlier in this chapter, three features of the aluminium producers supplied by the SWPC system are of interest: firstly, the smelter installed in 1906 was small by modern standards, requiring a power input of only 15 MW; secondly, the size of the smelter was then gradually increased resulting in a gradual increase in demand**; and, thirdly

* See footnote to p144.

** However, in the late 1920s, although the smelter capacity was increased, the power demand actually fell, for a time, as a result of the introduction of improved processes.

an integrated aluminium industry was created including local fabricating facilities.

b) Uganda: Compared with Kenya, Ghana and a number of other British colonies in Africa, the development of the electrical power system in Uganda, before 1950, was relatively slow. Although there had been some speculation by early travellers on the hydroelectric potential of the Nile no serious study of this was made until 1935[246]. At that time the output from the most promising site, at the Owen Falls, was considered to be too large for the existing demand and further thermal power stations were, therefore, constructed. By 1947 the system load had grown sufficiently to justify proceeding with the Owen Falls Project. It was believed that it would provide cheap power in sufficient excess to stimulate industrial development. In its final form, the capacity of the project was increased from 90 MW to 150 MW (ten 15 MW sets) the first two sets being commissioned in 1954 and the remaining eight entering operation progressively until 1968. A policy of stimulating consumption prior to the commissioning of the first sets was successful, as can be seen in Figure 33. Thereafter, between 1954 and 1956, the growth in consumption fell to rates considerably below those on which the financial calculations for the Owen Falls Project had been based. The rapid industrialization which had been forecast was, apparently, not taking place and Amann (1969) studied the reasons for this slow response by industrialists. The industries which, it had been thought, would use the new hydroelectricity included iron and steel, chemicals, copper refining, cement, textiles and, following the example of the TVA, super phosphate fertilizers. Almost without exception, Amann found, the financial, administrative and technical difficulties of establishing these industries had been underestimated. In a number of cases the Government was forced to provide the major initiative but, even then, plans ran at least five years behind schedule. More important, in many of the industries considered, the cost of electrical energy did not have a major effect on the establishment of new industries because it accounted for such a small proportion of total production costs. Wilson (1967) concluded that, although:

> at that time the most optimistic expected that rapid industrialization would alter the basis of the whole

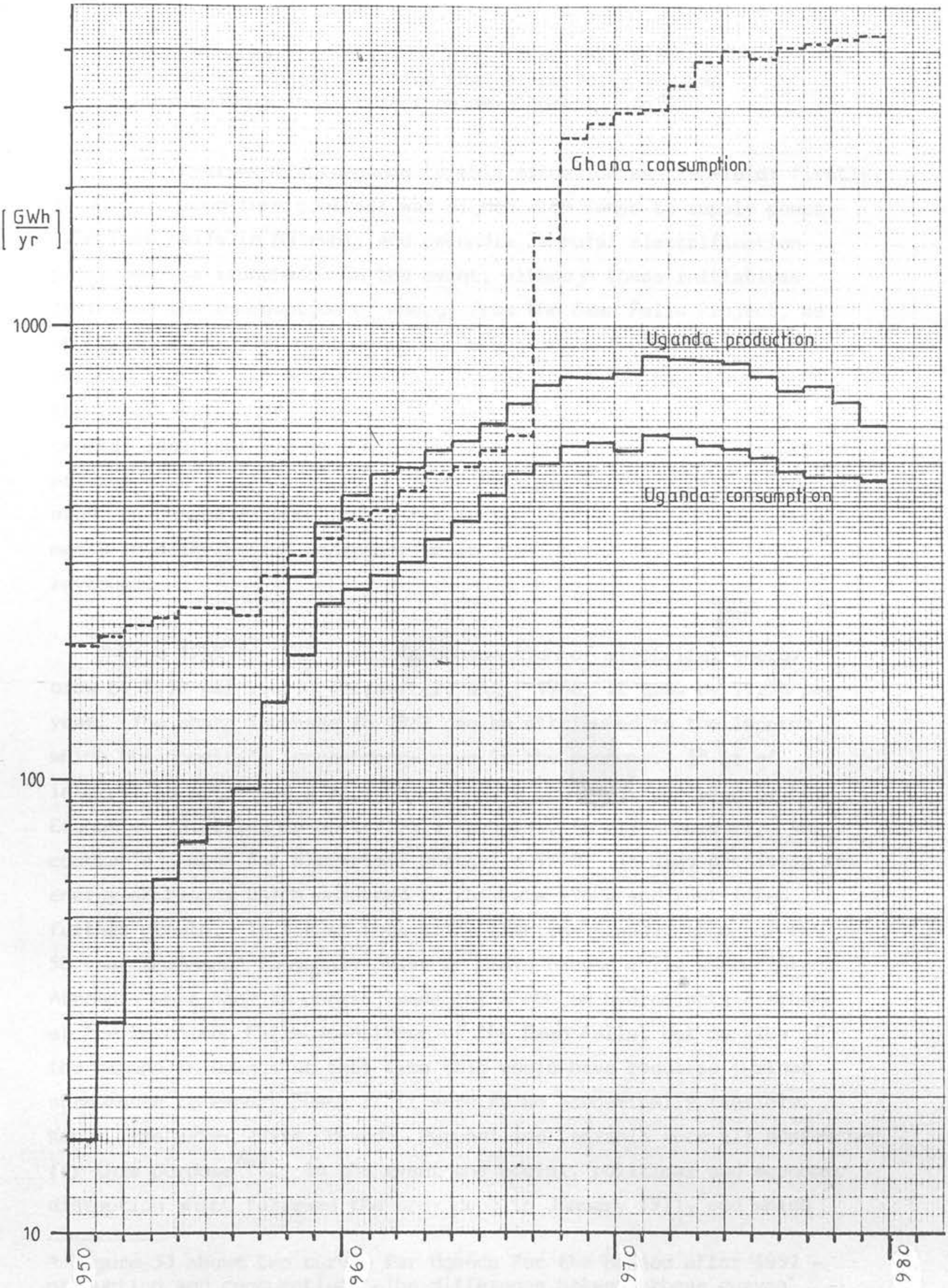


Figure 33: Gross consumption and production of electrical energy in Ghana and Uganda 1950-79.

Source: UN (1976, 1978 and 1981).

> Uganda economy ... it is now clear that this extreme optimism was unjustified and that electricity has had a surprisingly small effect on development. (p102)

The Government's response to this situation was two-fold: firstly, in 1955, a long-term contract was signed with Kenya to supply power from Owen Falls to Nairobi; and secondly, a rural electrification programme was launched. In the event, although these initiatives increased the consumption of energy from the Owen Falls Project, as shown in Figure 33*, neither made a significant contribution towards paying back the project's capital. Under the Kenya power agreement, the tariff rates were very low and provided little excess revenue for capital repayment (in 1959 Kenya took 41% of the project's output and provided 12% of its revenue). With the rural electrification programme, each new consumer connected to the system required additional investments in distribution equipment which also had to be repaid from revenues.

From 1959 to 1962 Uganda's consumption of electrical energy grew by 7.5% per year. Thereafter, until 1966, it grew by 11.5% per year. The sharp increase in 1962 can be attributed to the impetus which the country's independence gave to the economy. It is of interest to note that a study of Uganda's economy undertaken by the Economist Intelligence Unit (1957) forecast, fairly accurately, the country's demand for electrical energy in 1970. It also predicted the energy shortages which occurred in the late 1960s and restricted further growth. It was at this point that the disadvantages of the 50 year agreement to supply power to Kenya became fully appreciated. Attempts were made to obtain loans for a 600 MW hydroelectric scheme at the Murchison Falls, downstream of the Owen Falls, but in view of the demand in Uganda at that time this would have required further agreements to export power if it were to be economically feasible. Kenya, the Sudan, Zaire, Rwanda, Burundi and Tanzania were all approached for this purpose[247]. In the event the social, political and economic disruption which followed the army coup in January 1971, and which

* Figure 33 shows two curves for Uganda for the period after 1957 - production and consumption. The difference between these curves indicates the amount of energy exported to Kenya.

brought to power Idi Amin, produced a steady decline in the consumption of electrical energy in Uganda throughout the 1970s.

The example of Uganda is of interest because it is an example of, what Amann (1969) terms, 'unbalanced growth' - the policy of creating excess generating capacity in the belief that it will stimulate rapid industrialization. This pattern of growth is generally observed in systems linked to large hydroelecteic projects. For the policy to be successful the country must already have reached a certain level of economic development and be capable of directing the pressures created by having excess capacity into government initiatives to promote industry. However, cheap power is only one of many factors which determine the success of such initiatives. Alternative responses made by Uganda in the face of excess capacity, the export of excess power and the rural electrification programme, were both in the long-term, unsatisfactory.

c) Ghana: The Volta River Project has been considered above. Before the completion of the project, in 1967, the consumption of electrical power in Ghana had grown at a steady rate which reflected increased comsumption for agricultural processing, by the gold and bauxite mines and also by the beginnings of a manufacturing sector. From 1950 to 1957 the annual rate of growth was over 5% and, following independence, in 1957, a growth rate of almost 8% was established up to the mid 1960s. The completion of the Volta River Project brought an increase in consumption from 574 GWh/yr to 2 589 GWh/yr in just two years, but this was only possible because the building of the smelter had been planned to coincide with the completion of the dam. Since then electricity consumption has continued to grow although at an ever declining rate. From 1973 to 1979 the average annual growth rate was about 2%. Output has grown at a slightly faster rate than this as a result of an agreement, brought into effect in 1973, to supply small amounts of power to the neighbouring states of Togo and Benin (Dahomey).

As mentioned earlier, the building of the smelter enabled Ghana to acquire a large hydroelectric scheme which could not otherwise have been built but the arrangement did little to stimulate other industry in the country. Nor has the project helped to provide a long-term solution to the problem of meeting rising demand for electrical energy in the country; with the bulk of its output committed, in a long-term agreement, to supplying the smelter there is little excess power available for other industrial consumers. It has, therefore, been necessary to find alternative sources of power to meet such demands. This has led to the building of a combined hydroelectric and irrigation project, at Kpong, downstream of Akosombo[248]. Construction of this dam began in 1977 and is now completed. It remains to be seen whether this new project will prove any more successful in stimulating industrial development in the country.

The electricity supply industry in Mozambique

Statistics, drawn from different sources, which relate to the supply of electrical energy in Mozambique are frequently incompatible[249]. Data drawn from, what are believed to be , the more reliable sources have been used to provide estimates of annual consumption of electrical energy from 1950 to 1979, see Figure 34.

In the early years, private generation by industrial consumers, such as the Sena Sugar Estates, accounted for a significant proportion of the total electricity consumed in Mozambique. Up to the late 1950s over half of the consumption was produced privately. Thereafter, although the figures for private production continued to rise, the output from public systems grew at a much faster rate so that by 1970 private production accounted for only about 15% of the total. A significant factor in the increasing growth of the public supply systems was the entry into production, in November, 1953, of the public supply company Sociedade Hidroeléctrica do Revué (SHER), created for the purpose of generating and distributing bulk power from the Revué River. This was followed, in September, 1959, by the first output from the system built by the Portuguese Colonial Development Corporation, Sociedade Nacional de Estudo e Financiamento de Empreendimentos Ultramarinos (SONEFE), which had been given the responsibility for generating and distributing bulk power supplies in the area around Maputo. In the case of SONEFE, production was mainly by thermal power generation using coal imported from the RSA* but as demand has grown, and the plant

* The cost of transportation made it uneconomic to use coal from Moatize.

has become older, the system has become increasingly dependent on bulk purchases of electrical energy from the RSA. SHER, on the other hand, was able to exploit the hydroelectric resources of the Revué. These have been sufficient, not only to supply the needs of Beira and Chimoio (formerly Vila Pery), but also to provide excess for export to Mutare (formerly Umtali) in Zimbabwe.

Until the building of the Cabora Bassa Dam the Revué was the only river in Mozambique on which hydroelectric energy was being generated in appreciable quantity. The main power station, at Mavúzi, operated as a run-of-river scheme, has an installed capacity which was increased from an initial 13 MW in 1956 to 66 MW by 1962. A dam was then constructed, upstream of Mavúzi, at Chicamba and this, by regulating the river discharges, increased the potential for energy production at Mavúzi. In addition, a power station was built into the dam itself. At a later date the height of the dam was raised increasing the rated capacity of this station so that, by 1972, the total installed capacity on the Revué had reached about 140 MW and the annual energy production had passed 250 GWh. With a second power station at Mavúzi and a new scheme at Tzate it has been suggested that the annual energy production from the Revué could eventually be increased to 830 GWh[250].

In the south of Mozambique, close to the area of SONEFE's major loads, there are no comparable hydroelectric resources. Thermal generation has provided, therefore, the only means of local energy production. The main power station of the SONEFE system had an installed capacity of 57 MW in 1965. In that year the public utility produced 120 GWh of energy and required the importation of 68 x 10^3 t of coal; by the early 1970s these figures had doubled. A number of private and industrial generators were also operated in the region around Maputo.

In other parts of Mozambique the consumption of electrical energy was relatively low. Demand was met, therefore, by small local generating units most of which were driven by diesel engines.

The data presented in Figure 34 indicate the erratic pattern of

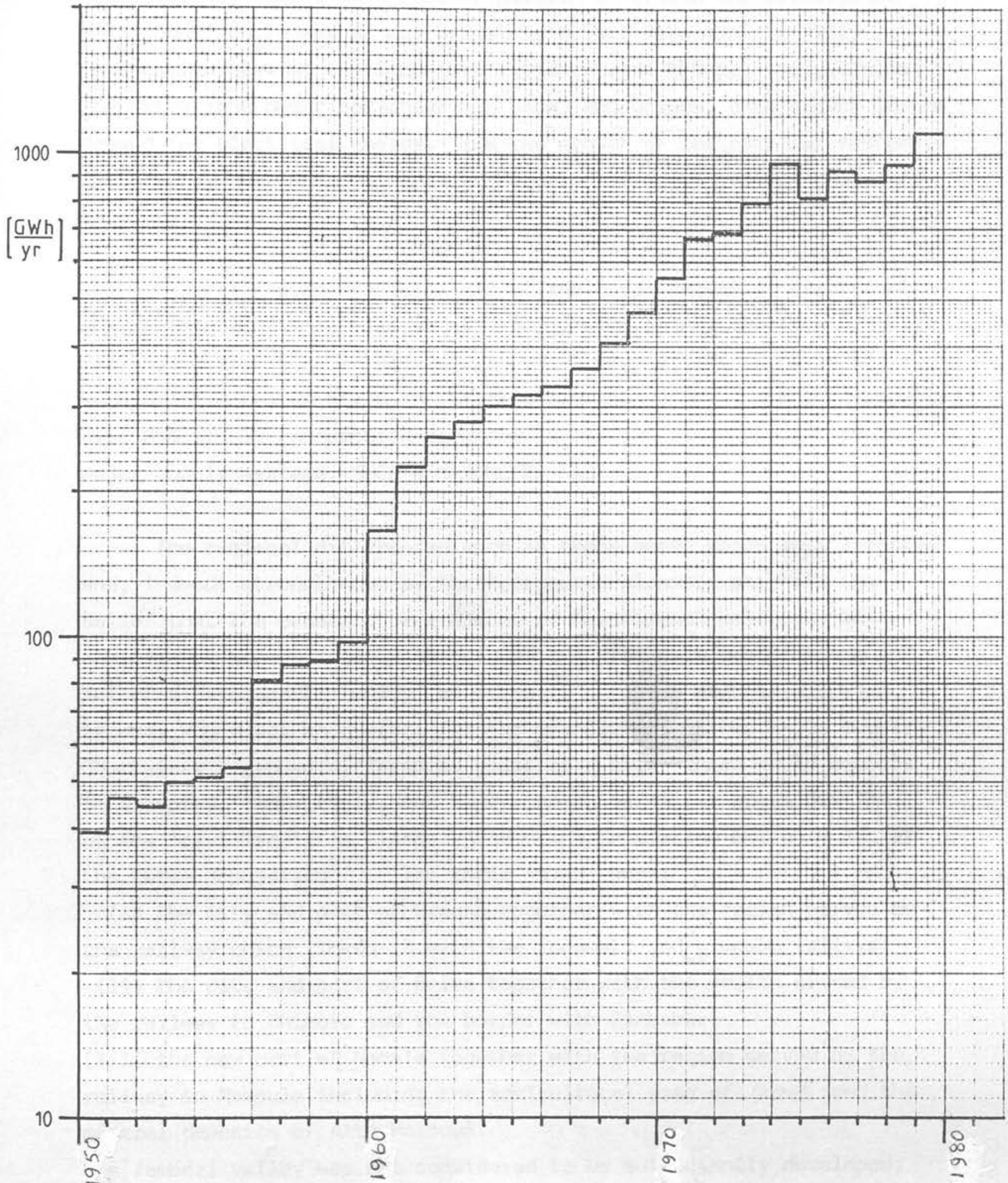


Figure 34: Gross consumption of electrical energy in Mozambique 1950-79.

Sources: see note 249.

growth of consumption, over the country as a whole, prior to 1962. From 1962 to 1967, a more regular pattern of growth was established with annual increases of approximately 6.5%. From 1967 to 1974, consumption grew at the much more rapid rate of 15% per year. Unlike the situations described above, in Ghana and Uganda, this growth in the demand for electrical energy, like the growth of the national economy, was severely disrupted at Mozambique's independence for reasons given earlier.

Figure 34 presents estimates of the total amount of electrical energy consumed in Mozambique but provides no information about regional differences in demand. An indication of the magnitude of such differences is given in the data of Table 23. As might be expected over 85% of all consumption occurred in the two regions in which the major supply systems, SHER and SONEFE, had been established.

The regional differences such as those noted above were accepted and, indeed, strengthened by the Portuguese planners who held the belief that the economic development of Mozambique could only be achieved by concentrating the bulk of the available resources in selected development 'poles' or 'axes'[251]. These regions, it was argued, would act as nucleii for the development of the whole country. Short-term regional differences would be a price which would have to be accepted. Inevitably, the zones chosen as 'axes' contained 75% of the 'civilized' (ie. largely European) population but only 25% of the total population[252]. The three 'axes' were:

(i) the city and port of Maputo together with the region served by the railway which linked it with the Incomati and Limpopo valleys;

(ii) the city and port of Beira together with the region served by the railway to Chimoio and the border with Zimbabwe;

(iii) the new port of Nacala together with the region served by the railway to Nampula including the agricultural area of Gurué and the mineral deposits of Alto Molócuè.

The Zambezi valley was not considered to be sufficiently developed, by the mid 1960s, to be included.

It should be noted that the first two 'axes' were served by the

Table 23: Regional differences in electricity production and consumption in Mozambique

	January to December 1965 (1)							December 1975 (2)	
	Total electricity consumption (GWh)	Provincial consumption as % of national	Electricity production by public utilities (GWh)	Public production as % of total production	Number of power stations	Installed capacity (MW)	Mean unit size (kW)	Electricity consumption (GWh)	Provincial consumption as % of National
Maputo	155	51	121	78	108	83.6	774	24.2 (4)	53
Gaza	3.2	1.0	2.8	89	66	4.8	72	1.0	2.1
Inhambane	1.3	0.4	1.1	89	46	2.6	43	0.27	0.6
Manica e Sofala	108	36	210 (3)	96	121	80.7	667	14.3	32
Tete	4.1	1.3	4.0	98	46	3.2	71	1.5	3.2
Zambézia	17.9	5.9	4.8	27	104	16.9	163	1.3	2.9
Nampula	11.5	3.8	6.5	57	118	14.8	125	2.1	4.6
Cabo Delgado	1.9	0.6	1.8	96	33	3.1	95	0.5	1.1
Niassa	0.8	0.3	0.8	100	24	1.4	57	0.16	0.4
Total (5)	304	-	352 (3)	85	666	210.5	316	45.3 (4)	

Notes: (1) Source: Serv. Aut6. Elec. (1965) Table III.
(2) Source: Dir. Nac. Estat. (Dec. 1975) p 33.
(3) Includes 111 GWh exported to Umtali.
(4) Includes 14 GWh imported from the RSA.
(5) Totals may not agree due to rounding errors.

electrical transmission networks of SONEFE and SHER respectively. The SONEFE network, by the early 1970s consisted of about 90 km of 30 kV primary distribution line together with a 275 kV line which carried the bulk power imports from the Escom system. The SHER network, by that time, included about 300 km of 110 kV primary distribution line linking Mavúzi with both Beira and Mutare and a separate 66 kV line of about 90 km to carry power to Chimoio, see Figure 36 below.

The supply of electrical power and the establishment of industry in the Zambezi basin

The first half of the present century saw little industrial, or commercial, activity in the lower Zambezi basin except in isolated enterprises which had been established to exploit single products - coal at Moatize, sugar at Marromeu and Luabo, coconut around Quelimane and timber around Inhaminga. Elsewhere, small urban centres acted as markets for the surrounding rural areas and as administrative and military headquarters.

The data of Table 24 provide a clear picture of the low level of development of electricity production in the lower Zambezi, in 1965, and the marked influence of the isolated enterprises, referred to above, on the siting of electrical generating capacity; the three generating units larger than 1 MW were sited at Moatize, Marromeu and Luabo respectively.

The least developed part of the basin was Tete Province where, if statistics for forty small generators not listed in Table 24 are included, the total installed capacity in 1965 was made up as follows: 7 publicly operated generators totalling 2.3 MW; and 39 private generators totalling 0.95 MW[253]. The total production of electrical energy that year was: public generation, 4 000 MWh; and private generation, 63 MWh. All the generators in Tete Province were operated on liquid fuel despite the mining of coal nearby, although, in the late 1960s, a forty-year-old coal fired station was installed in Tete after it had been declared obsolete in its previous location within Zimbabwe[254].

Table 24: Power stations of more than 50 kW capacity in the Zambezi basin in 1965

Province	Location	Operation	Number of units within given size range: 51 - 100 KW	101 - 1 000 KW	1 001 - 5 000 KW	5 001 - 20 000 KW
Tete	Tete	Private	1	1		
		Public		1		
	Moatize	Public			1	
	Furancungo	Private	1			
	Mutarara	Private	1			
Zambézia (part)	Chinde	Public		1		
	Mopeia	Public	1			
	Quelimane	Public		1		
	Luabo	Private				1
Sofala (part)	Inhaminga	Public		1		
	Marromeu	Public	1			
		Private			1	
TOTAL Zambezi basin			5	5	2	1

Source: Serv. Autó. Elec. (1965) taken from maps showing power station locations.

Information about the parts of the Zambezi basin within Sofala and Zambezia Provinces is less readily available because official statistics have generally been compiled only for complete provinces. Nevertheless, Falcão (1963) estimated that, in the whole of the basin within Mozambique, the consumption of electrical energy in 1959 amounted to 13.5 GWh, slightly over 10% of the total consumption in the country. Of this, the two large sugar factories, together with some small food processing units, consumed 10.5 GWh (78%); the mine at Moatize consumed 2.4 GWh (18%); the timber mills consumed 0.24 GWh; and other users, together, accounted for only 0.36 GWh. Equivalent figures for the whole region for subsequent years are not available but those for Tete Province by itself show some interesting features. In the 1950s the Moatize mine accounted for at least 90% of the energy consumed in the province. Thereafter, the proportion gradually fell reaching less than 65% by 1965. The fall was not due to a decrease in energy demand at the mine but to a dramatic increase in the demand by domestic consumers - especially the Europeans who arrived in Tete to work for the MFPZ. The trend continued until 1971 when only 36% of the 8.9 GWh consumed in Tete Province was for industrial use. Over the next year consumption quadrupled, to 37.1 GWh, as a result of high consumption of electrical energy associated with the construction of the Cabora Bassa Dam. As the dam neared completion, however, energy consumption fell back. The latest available published data show an annual consumption in Tete Province of 20 GWh of which only 43% was accounted for by 'industrial' consumption.

Neither in these data, nor in the available data for those parts of the lower Zambezi within Sofala and Zambezia Provinces, is there any indication of a diversification or expansion of industrial activity between 1950 and 1974. There had been no stimulation of industrial consumption in advance of the completion of the Cabora Bassa Project, as had occurred in Uganda. Reports by the MFPZ, including the *Plano Geral*, had considered details of possible industries which could be established in the Zambezi valley and which could provide a market for Cabora Bassa's energy, see Table 25. However, apart from the provisional agreement to build a pilot steel plant, referred to above, little had been achieved by 1974. By that stage, of course, the agreement to sell

Table 25: Industries proposed, in the *Plano Geral* for the Zambezi valley

Industry	Unit size	Period of operation	Investment (contos/unit)	Inputs per unit: Electrical Energy (GWh/yr)	Inputs per unit: Water ($m^3 \times 10^3$/yr)	Labour Demand per unit: Skilled	Labour Demand per unit: Unskilled	Labour Demand per unit: Seasonal
Milk products	10×10^3 l/day	all year	7 750	-	-	10	20	-
Tomato	150 t/day	Aug-Oct	9 000	0.1	0.3	15	60	120
Rice husking	0.8 t/hr	Jul-May	3 500	-	-	7	13	-
Sugar	60×10^3 t/yr	May-Oct	350 000	5.5	9.0	80	-	900
Starch/glucose	60×10^3 t/yr	all year	60 000	5.0	1.5	100	250	-
Cotton seed oil	15×10^3 t/yr	all year	45 000	12.5	-	75	60	-
Lucerne	2.3 t/hr	all year	1 600	-	-	-	3	-
Cattle food	10 t/yr	all year	16 000	-	-	6	16	-
Cotton 'ginning	1.8×10^3 t/yr	Jul-Nov	8 000	0.35	-	11	6	90
Cotton spinning	20×10^3 spindles	all year	60 000	3.5	0.15	25	320	-
Cotton weaving	400 looms	all year	85 000	2.5	-	27	430	-
Jute	3.8×10^6 sacks/yr	all year	45 000	2.5	-	N/A	N/A	-
Timber mills	6×10^3 m^3/yr	all year	3 000	-	-	11	60	-
Wood chip	50 t/day	all year	80 000	9.0	0.84	-	120	-
Celulose	33×10^3 t/yr	all year	250 000	37.0	22.0	160	80	-
Aluminium sulphate (electrolytic)	60×10^3 t/yr	all year	330 000	12.5	-	75	60	-
Steel	500×10^3 t/yr	all year	N/A	925.0	17.0	N/A	N/A	-
Coke	500×10^3 t/yr	all year	N/A	3.0-4.5	1.9-3.6	N/A	N/A	-

Source: *Plano Geral, Texto*, Tables 41, 42, 44 and 45 - N/A indicates data not available.

power to Escom had removed the urgency from attempts to create local demand for Cabora Bassa's energy. Study of the data in Table 25 indicates that, even with a full-size steel plant, it would have taken a considerable period to establish a local demand for even 10% of Cabora Bassa's energy potential by means of the industries considered in the *Plano Geral*.

The choice of d.c. transmission for the power supply from Cabora Bassa to the RSA and its implications for the power supply to Maputo

When, after the publication of the *Plano Geral*, the RSA began to show an interest in the possibility of importing power from Cabora Bassa, Portuguese engineers realised that the construction of a high voltage transmission line for this purpose might also provide a solution to the pressing problem of supplementing the supply of power to the SONEFE system in the region around Maputo. Correia (1967) reported that a 500 kV a.c. transmission line was under consideration. The proposed line would have had a substation at Massingir, from where power could be supported to both the Escom and SONEFE networks. A substation at Chimoio was also planned from where a link with the SHER grid could have been made. In this way the major electrical systems in southern Mozambique could have been linked together and to Cabora Bassa. Yet, for the foreseeable future, the total demand of the SONEFE and SHER systems would have been small relative to the output of the Cabora Bassa Project and, therefore, the benefits to Mozambique of such a system were considered to be less important than the need to obtain a firm commitment from Escom over the purchase of power from Cabora Bassa. For this reason, the alternative of using a d.c. transmission line, which would, effectively, have prevented links with the SONEFE and SHER systems from being created, was not dismissed.

For a time, the relative advantages and disadvantages of a.c. and d.c. transmission systems were keenly debated by Portuguese engineers who were unable to reach a consensus on which should be adopted. Moura (1968), for example, after examining the technical aspects of the two alternatives and attempting an economic evaluation of them, found that:

> For the transport of energy from Cabora Bassa to the Escom network it cannot be concluded that a.c. or d.c. would be the better solution. In the present phase of the studies neither the available technical information nor the indications of costs can be considered adequate, by themselves, to form the basis for a decision. (p192 , writer's translation)

In the initial documents for the Cabora Bassa Project, tender estimates were, in fact, invited for each of the two alternatives.

The principal factors considered in the debate on the technical and economic advantages and disadvantages of the two alternatives are summarized as follows[255]:

(i) for line lengths of over, say, 500 km a.c. transmission gives rise, increasingly, to problems of dynamic instability and internal overvoltages which increase the likelihood of system faults and for which large reactive compensators must be provided;

(ii) d.c. systems introduce problems as regards both voltage transformation and switching which, as a result, make the design of systems and equipment more complex and make the provision of tapping points along a transmission line extremely expensive;

(iii) communications and protection equipment in a d.c. system is highly specialized and expensive;

(iv) in the late 1960s, the end equipment required for high voltage a.c. systems was both better tested in service and more readily available than that for equivalent d.c. systems, as a result, it was likely to be cheaper and more reliable;

(v) the cost of the line itself is lower for d.c. transmission because the insulation required for the same effective voltage is less and only two conductors are needed instead of three;

(vi) for transmission of the same quantity of power through the same size of conductor the line losses are also lower for a d.c. system;

(vii) if one conductor in a normal three-phase a.c. line develops a sustained earth fault the whole supply is lost whereas, provided that adequate earth points have been provided, a d.c. line can continue to operate at reduced power through a single conductor; and

(viii) by using a d.c. link the primary a.c. transmission systems in the RSA and Mozambique remain independent and need not be operated in sychronism.

In economic terms it was generally agreed, at the time, that d.c. transmission would be preferable for very long lines but the various authorities differed on what the critical length should be; values from 750 km to 1 450 km had been suggested[256]. Thus, for the transmission distance involved in the Cabora Bassa Project, 1 400 km, it was thought that there would probably have been no great cost advantage from either type of system as far as Escom was concerned. For Mozambique, however, the a.c. alternative, by allowing tapping points for the supply of power to the southern part of the country, would have been more attractive since it would have saved further investment in generating and transmission equipment to meet the growing demand for power in that region.

As mentioned above, the engineers of Escom had considerable influence over the design selected for the transmission system. It has not been possible to determine the reasons for their final choice of d.c. transmission. Nevertheless. the following factors were probably influencial in that decision*:

(i) it isolated the Escom network from stability problems which might have arisen from being linked by a.c. to the Cabora Bassa Project and the existing a.c. systems in Mozambique;

(ii) by preventing tapping points it made it less likely that, at some future date, the amount of power being sold to Escom would be reduced in order to supply increasing demand in Mozambique; and

(iii) for the same reason, the d.c. link effectively prevented alternative markets for Cabora Bassa's power from being developed within Mozambique thus making the project more dependent on the RSA and, therefore, less likely to be affected by any changes which might occur in relations between the two countries.

In other words, d.c. transmission was likely to give the RSA

* The ZAMCO consortium which won the contract for the Cabora Bassa Project also had an interest in securing a decision in favour of a d.c. system. The German group of companies, Siemens-AEG-Brown Boveri, which was part of ZAMCO, had invested large sums in research into d.c. transmission without having won a single major contract.

greater control over its supply and to increase Mozambique's dependence on the RSA for the future operation of the project. Mozambique's dependence on the RSA was increased by the subsequent decision described below, to supply the SONEFE grid with power from Escom.

In the 1960s the demand on the SONEFE grid grew rapidly as a result of the rapid industrial development which was occuring in and around Lourenço Marques (Maputo). By 1970, thermal power stations provided a total generating capacity of over 57 MW[257]. However, ageing equipment and ever increasing demand provoked an urgent need to supplement the supply. Possible hydroelectric sources had been considered including the addition of a power station to the proposed irrigation dam at Massingir on the Elefantes (250 km from Maputo) and a proposed scheme at Massangena on the Save (500 km from Maputo). Economic factors affecting the transport of power from these two sources were evaluated by da Silva (1964) who concluded that the Massingir scheme, at least, appeared to be feasible in this respect. A final decision was delayed, however, in the anticipation that the Cabora Bassa Project would provide a solution to SONEFE's supply problems. Thus, by the time that final agreement had been reached with Escom and the d.c. transmission system from Cabora Bassa selected, the need to find an alternative supply to supplement the capacity of the SONEFE system had become urgent. An early agreement with Escom was, therefore, sought whereby the SONEFE system would import electrical power from Escom along a new 275 kV a.c. transmission line which would be built from Komatipoort. The line was constructed before the Cabora Bassa Project had been completed and was in operation by 1972.

In 1973, the SONEFE grid took 150 GWh of energy from Escom with a peak demand of 25 - 30 MW, and by 1976 purchases had increased to 200 GWh/yr. Although a decline in consumption occurred subsequently a recent programme of electrification for the suburbs and villages around Maputo has created a maximum demand on the former SONEFE system of 50 MW, of which 35 MW is accounted for by the demand within Maputo[258]. The bulk of the energy is supplied from Escom but the Mozambican authorities prefer to regard it as a re-importation of energy from Cabora Bassa[259]. The ageing thermal power stations can still be operated for limited periods. Their use requires coal to be imported and by far the cheapest source for such imports is the RSA. No details of the agreement whereby power is purchased from Escom are known, but it is understood that the maximum load is, at present, limited to 75 MW both by the contract provisions and the capacity of the transmission line[260].

The Portuguese authorities regarded the arrangement to buy power from Escom as a temporary measure. They believed that, with the completion of the North Bank Power Station, the RSA would undertake to buy further quantities of bulk power from Cabora Bassa which would necessitate the building of a new transmission line. For this, the Portuguese, favoured an a.c. system which, by being operated in tandem with the existing d.c. line, would not suffer as greatly from dynamic instability as an isolated a.c. line whilst enabling the desired tapping points for the SHER and SONEFE grids to be made[261].

The problem of ensuring that Maputo's future demand for electrical power is met remains unresolved. The two simplest and cheapest options are to make increased purchases of power from Escom or to build a new thermal power station which would be supplied by coal from the RSA. In both cases dependence on the RSA would be increased. Nevertheless, a thermal power station could be supplied with coal from other sources, if this was considered desirable even though this would increase the cost of the energy produced. The possibility of building a power station at the Massingir Dam has been re-examined but reservations have been expressed about the hydrological aspects of this scheme[262]; again, it is dependent on the RSA which consumes large quantities of water from the Elephantes upstream of Massingir. Attempts to supply Maputo with power directly from Cabora Bassa would be extremely expensive at the present level of demand, whether it were achieved by building a new a.c. system or by attempting to tap the existing d.c. system. As well as presenting some technical difficulty, the latter course would also be strongly opposed by the RSA; besides the special equipment which would be required for the convertor station it would be necessary to install equipment to provide synchronous compensation to balance the effect of the a.c. grid on the supply[263]. If, at some future date, Escom ceased to buy power from Cabora Bassa it might be possible for Mozambique to purchase some of the equipment from the Apollo substation and install it in a new substation within southern Mozambique. This would also give rise to high energy costs at the present level of consumption. For details of the d.c. system see Figure 35.

The supply of power to the central and northern regions of Mozambique

In 1967, before detailed agreement with Escom had been reached over the purchase of power from Cabora Bassa, Hidrotécnica Portuguesa published a paper in which the expected pattern of future consumption of the ouptut from Cabora Bassa was set out. At that time it was envisaged that Cabora Bassa would supply power both to Maputo and the region around Tete, see Table 26a. A provision was also made, in the proposals for the ultimate development of the project, for some power to be exported to other neighbouring countries, see Table 26b. It may be seen from these tables that, for each stage of the proposed development, the power demand within Mozambique was foreseen as being approximately 15% of the demand arising from the agreement with Escom. (In terms of energy consumption the proportion would have been closer to 10% by virtue of the higher load factors of Escom's consumption).

In the final agreement, signed in 1969, Escom was persuaded by the Portuguese authorities to take larger quantities of power at an early stage, than those forseen in the 1967 report, in order to provide increased revenue to finance the dam and the South Bank Station. In return, however, Escom stipulated that proposals to export power to other neighbouring countries must be curtailed and that the provisions for the supply of power to the Maputo and Tete regions must be revised. The supply of power to Maputo became regulated by the subsequent agreement to construct a supply line from the Escom grid, as described above. Few details of the allowance made for demand in the Tete region are known beyond those contained in accounts of discussions concerning the siting of a steel industry at Tete referred to earlier. It is worth quoting one such account at length since it presents the dilemma in which the Portuguese engineers found themselves as construction work on the Cabora Bassa Project started:

In order to supply this future power consumption [including new

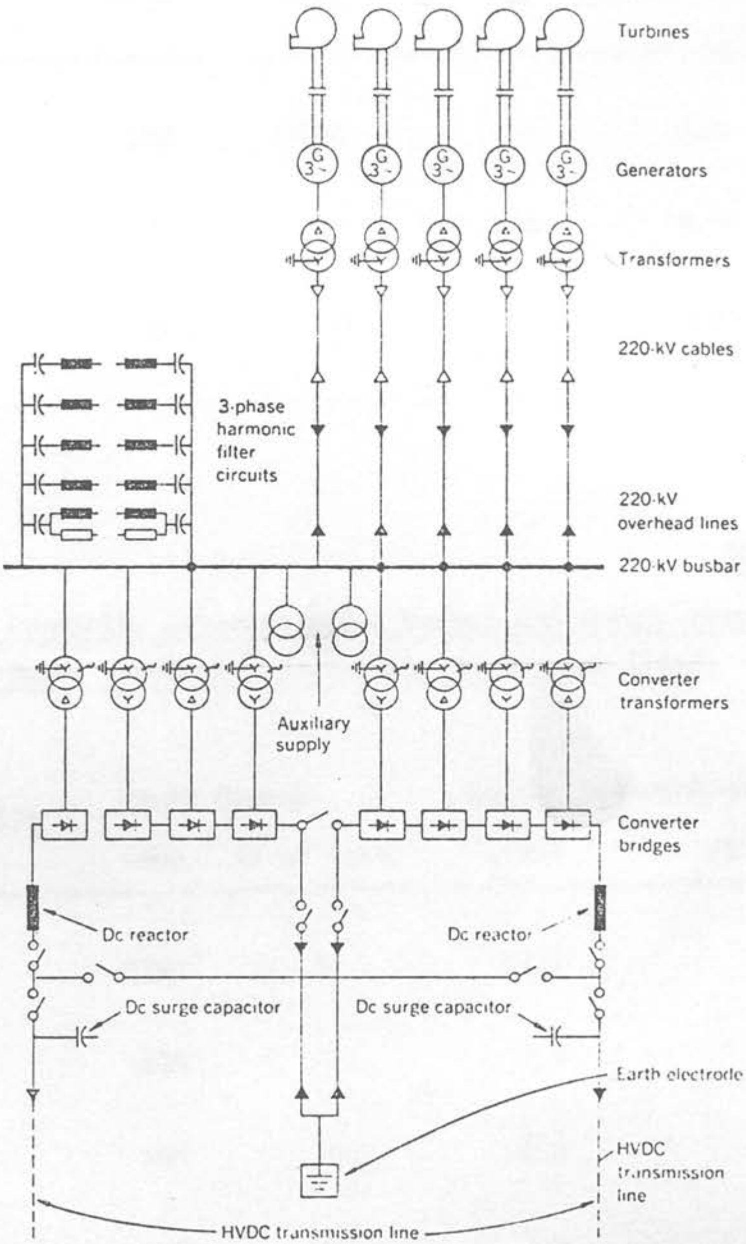


Figure 35: Diagram of the electromechanical equipment of the Cabora Bassa high voltage d.c. transmission system.

Source: Klein et al.(1974).

Table 26a: Predicted growth in power demand from Cabora Bassa based on Hidrotécnica Portuguesa (1967)

Area of supply	Predicted power demand (MW) 1974	1977	1980	Expected load factor
Escom	500	1000	1500	0.8
Maputo	50	100	150	0.57
Tete	30	50	75	0.46

Table 26b: Predicted ultimate power demand and energy consumption from Cabora Bassa based on Hidrotécnica Portuguesa (1967)

Area of supply	Power demand (MW)	(% of total)	Energy consumption (TWh)	(% of total)
Escom	1760	59	12.3	65.5
Maputo	200	7	1.0	5.3
Tete	100	3.5	0.4	2.1
Other export	650	22	3.5	18.6
Losses	(250)	8.5	1.6	8.5
Total with losses	2960	--	18.8	--

industries in the Zambezi basin] the Cabora Bassa North Bank Station, which is not part of the present contract, will be required. However, its initial operation could only be envisaged if there is sufficient guaranteed consumption to allow it to operate economically.

Until then, other solutions will have to be sought such as obtaining from the RSA an agreement to reduce its contracted power supply and to receive peak energy instead of the base-load energy which it would relinquish.

The management of these discussions with the RSA had seemed difficult because the agreements with Escom had been reached a short time before and this, the principal consumer, as is normal, had always stressed the need to include a reserve generator set in determining the price of base-load energy if it were to be properly guaranteed.

On the other hand, in the final phase of the negotiations with the RSA, it was, in fact, the Portuguese delegation which insisted that Escom should take a contract for an increased amount of energy in order to obtain the maximum revenue possible from the operation of the South Bank Station and because the possible consumers in Mozambique had not given any guarantee of utilization.

However, in contacts established since August [1970] with the Escom officials, in which a frank exchange of opinions took place concerning the benefit which the growth of consumption presented to the GPZ, an indication of principle was obtained from that organization to the effect that it was able to foresee an agreement being established which would allow the 415 MW corresponding to the reserve set to be considered for use by other consumers until the North Bank Station begins operating[264].

Officials of the GPZ who wrote the above passage suggested, in it, two ways in which the Escom agreement might be modified to provide the required power for consumption in the Tete region. The first, to persuade Escom to relinquish a proportion of its bulk energy purchases and accept, instead, peak energy, is only applicable in situations where a project has insufficient storage capacity to guarantee the required firm power output but has excess installed capacity. This is certainly not the case with the Cabora Bassa Project, as it now stands, where there is little likelihood of a shortage of water but the contracted output constitutes a high proportion of the maximum which could be provided given the present capacity of the generation and transmission equipment (see Simulation 1, Chapter 3)*. The second suggestion is to

* The RPT studies have shown that a certain amount of secondary energy could be generated for a few months of most years but this is unpredictable and could, in no way, be regarded as a source of peak energy.

allow 'reserve' generating capacity to be used for other consumers. This suggestion will be considered below, in rather more detail, by reference to the simulations of Chapter 3. However, it should be noted both that such a suggestion was only considered to be a temporary arrangement until the North Bank Station could be built and that should any of the other sets require repair or maintenance the consumers relying on the output from the 'reserve' set would, presumably, lose their source of supply.

The situation has been clarified through the results of the simulations described in Chapter 3. These simulations have shown that it is the very existence of a clause in the present supply agreement, allowing Escom to make peak energy purchases, which imposes the principal constraint on Mozambique's ability to obtain useful output for internal consumption from Cabora Bassa. If Escom were to relinquish this right and agree to purchase only the firm power component of the present contract (calculated as 1605 MW at turbine shaft) then, according to the results of Simulation 4, Mozambique could derive up to 100 MW of power from the Cabora Bassa Project with a relatively high degree of security.

As the results of Table 16, in Chapter 3, indicate the concept of a 'reserve' generator is not very applicable: on the one hand, for a large proportion of the time, it is likely that an extra 100 MW could be generated from the four sets which are providing Escom's supply; and, on the other hand, for a small proportion of the time, operation of the 'reserve' generating set would be required even to supply the full output at present required by Escom. Whether or not an extra 100 MW of firm output is sought there will be periods, of up to three months, when all five sets must be operated to give the required output. Under such circumstances the schedule for the regular maintenance of the generating equipment at Cabora Bassa must be organized to ensure maximum reliability during the critical months. Furthermore, an agreement must be reached with Escom over a satisfactory procedure to adopt should a generator break down during a critical period, including possible compensation payments. It is almost certain that such an arrangement is included in the present contract, but it may need to be revised if

Mozambique begins to take appreciable amounts of power from the project.

As far as the present authorities in Mozambique are concerned output is, at present, being sought from Cabora Bassa to meet increasing demand in the central and northern regions of Mozambique. Reference was made, in the introduction to this thesis, to some of the larger projects which have been proposed for these regions. However, many of the projects would be in areas already served by the SHER system. Of the remainder, the only new major consumers of electrical power would be a textile mill at Mocuba, the exploitation of mineral deposits at Alto Molócuè and the Caia aluminium smelter which has been discussed in detail above. Such projects, if implemented, would bring a dramatic increase in demand in northern Mozambique but the increase would be unlikely to exceed 100 MW by the end of the decade if the aluminium smelter is excluded*.

Since the Mozambican authorities have, apparently, opted to meet this expected increase in demand with power from Cabora Bassa it has been necessary for them to begin building an entirely new electrical transmission network in the region. Details of this network are shown in Figure 36. Construction began on the first phase, the line from Songo to Mocuba, in 1980 and is due to be completed by December 1982. By this time it is hoped that some of the projects planned to use the power will have been completed.

Before considering the details of the project, and its possible implications for the region, a brief account of earlier proposals for electricity supply is provided to set the background to current thought.

Prior to independence the northern region of Mozambique, the provinces of Zambezia, Nampula, Cabo Delgado and Niassa, was relatively poorly supplied with electrical energy. The data of Table 23 indicate that this region accounted for about 10% of the total consumption of

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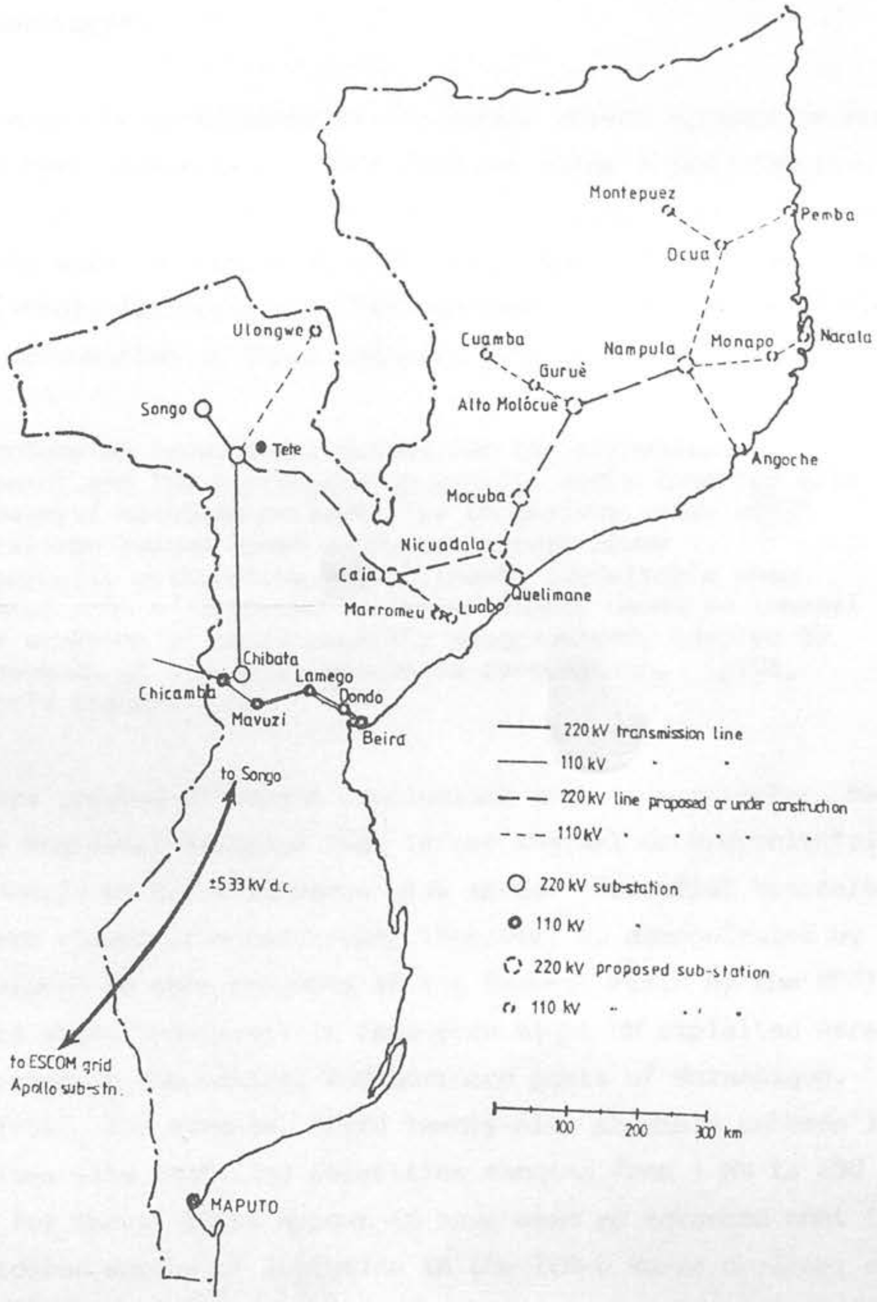
* *Tempo*, Maputo (11 May 1980) reported that the planned textile mill would increase demand around Mocuba from the present level of 2 MW to about 40 MW by 1987 but this may be an over-estimate.

Figure 36: The proposed a.c. transmission system for central and northern regions of Mozambique.



Principal source: *Tempo*, Maputo, 500 (11/5/80).

electricity in the country. Moreover, this percentage appears to have been decreasing in recent years. The central region, by contrast, was rather better served since it includes the established hydroelectric projects and transmission network of SHER. However, even in this region, in towns not connected to the SHER system, as in the whole of the northern region, the main source of supply was from isolated diesel generators*.

Although the development of the public supply systems in regions other than that served by the SHER grid was given a low priority, by the Portuguese authorities, technical and economic aspects of proposed developments were considered at some length by Portuguese engineers. Da Silva (1964), for example, after considering the characteristics of energy consumption in these regions, concluded that:

> The volume of investments needed for the transmission equipment and the corresponding capital costs together with the massive maintenance costs, by themselves, make a centralized system based on hydroelectric power ... economically prohibitive or, at least, inadvisable when compared with a dispersed system of supply based on thermal power stations of small capacity progressively adapted to the demands of a natural growth in consumption. (p108, writer's translation)

Others reached different conclusions and, in particular, many Portuguese engineers believed that larger thermal or hydroelectric stations should be built to serve wide areas. Potential hydroelectric schemes were viewed with particular interest, as demonstrated by the emphasis placed on such projects in the Zambezi basin by the MFPZ. Other sites where hydroelectric resources might be exploited were sought throughout the central and northern parts of Mozambique. Cabrita (1964), for example, lists twenty-nine possible schemes in these regions with installed capacities ranging from 1 MW to 650 MW. The plans for two of these appear to have been so advanced that they were considered worthy of inclusion in the ICOLD *World Register of Large Dams* (1973). However, on closer inspection, the hydrological aspects of many of these projects may have proved as unsatisfactory

* A few small hydroelectric schemes are in operation, for example in the Licango basin in Zambézia Province.

as those of many of the projects proposed by the MFPZ, see Chapter 2.

A coal-fired power station located by the mine at Moatize, was also considered in the *Plano Geral* and found to be more economical than the proposed hydroelectric schemes for installed capacities of up to 50 MW and possibly up to 100 MW[265].

Thus, Portuguese engineers had considered a number of alternative sources of electrical energy which might have served an integrated transmission network. But, when work began on the construction of the Cabora Bassa Dam it was, naturally, assumed that any integrated grid would derive a large proportion of its supply from this project. In 1973, work began on building a 220 kV, a.c. line from Songo to Chipata in order to link Cabora Bassa with the SHER system. At that time it was intended that this line would carry up to 96 MW by 1981 and that half the energy would be for export to Mutare[266]. The line has been completed but its present pattern of use is unknown. In the northern regions it had originally been intended to establish local, 150 kV, a.c. transmission networks based on hydroelectric schemes on the rivers Molócuè and Lúrio[267], but as early as 1968 a transmission line similar to that currently being constructed was proposed to link the major centres of consumption with Cabora Bassa[268].

The 220 kV transmission line under construction, as shown in Figure 36, will link Songo with Caia, Mocuba, Alto Molócuè and Nampula, a total length of 1 000 km. Links would be provided to other load centres by means of 110 kV, a.c. lines. Work on the first part of this project, the line to Mocuba, has made considerable progress. This work, which is being undertaken by Italian and French companies, under the direction of Swedish consulting engineers, is expected to cost approximately US $ 120 million[269].

A number of questions about both economic and technical aspects of this project have not been resolved. On the economic side, the project requires a considerable investment in relation to the revenue it is likely to generate. On the basis of da Silva's work, in 1964, a 22 kV, a.c. line of 450 km length should carry at least 75 MW if it is to transmit power at rates which would be competitive with local diesel generation[270]. The line to Mocuba will, in fact, be over 700 km in length and is unlikely to carry loads of this magnitude for a number of years. Although economic factors are likely to have changed since da Silva's study his results suggest that returns from the project are likely to be very poor in the first decade of its operation. (To take just one item out of the costs considered by da Silva, the cost of maintaining the area under the line free of vegetation would be considerable; it is known that the CAPC spends the equivalent of over US $ 100 000 each year on such work for the 500 km of line which it operates within Zambia[271]). The initial investment is also very high, in relation to the country's present capacity to earn export revenue. It seems, on the face of it, unwise to tie such a large capital sum into a project whose benefits may be realized only in the next decade.

A number of technical aspects of the project have to be considered when the project goes into operation. Firstly, the transient stability of such a long a.c. transmission line (ultimately planned to reach Pemba, a distance of over 1 300 km), fed by a single source at one end, will call for the provision of large amounts of reactive compensation along the line[272]. Secondly, because of the high capacitance, a large energizing current will be taken by the line and will make the transmission of small amounts of power extremely costly. Thirdly, since power would be supplied from a single source at one end of the line, a sustained fault on the transmission line or in the substation equipment would deprive virtually the whole of northern Mozambique of its supply of electrical energy. Fourthly, there are, at present, very few Mozambican electrical engineers and, probably, none with any experience of operating and maintaining a large transmission system of this nature. Finally, it has been shown from the results of the simulations in Chapter 3 that, with the present installed capacity at Cabora Bassa, very little, if any, firm power could be made available to consumers in Mozambique without violating the terms of the power contract with Escom. If Mozambique wishes to pursue industrialization it must have a reliable and guaranteed high level of supply security from its single major source. Without the North Bank Station, this could only be achieved by ensuring that it is Escom's supply rather than Mozambique's which is reduced should there be any drop in output from Cabora Bassa resulting, for example, from machine failure. Such an operating policy would entail compensation payments to Escom which would make Mozambique's supply significantly more expensive.

There is a strong political motivation for the Mozambican authorities to seek to create an integrated electrical power system in the country which would help to bring tangible benefits to Mozambique from the Cabora Bassa Project and reduce its dependence on imported diesel fuel. Nevertheless, it is difficult to reach any other conclusion from the foregoing discussion than that the Mozambican authorities were ill-advised, at the present time, in undertaking the northern grid project. Furthermore, once the section to Mocuba is completed, it would be of clear advantage to make a careful re-assessment before proceeding rapidly to further stages of the project.

Financial and contractual agreements governing the operation of the Cabora Bassa Project*

Construction of the Cabora Bassa Dam, the South Bank Power Station, and the d.c. transmission line to the RSA were undertaken by the single consortium, ZAMCO, referred to earlier. The Portuguese Government, being in no position to provide more than a small proportion of the capital required for the project, stipulated that the consortium should provide the bulk of the capital, at interest rates of no more than 6%, on the basis that loans would be repayed, through the sale of power to Escom, over a period of twenty years. Since commerical banks would have been unable to offer credit on such favourable terms the consortium members were obliged to seek it in the form of export credits from their respective governments, principally, France, Germany, and the RSA. The response of these governments was strongly influenced by political considerations. The French authorities, seeking greater political and economic involvement in Africa and wishing to provide overseas contracts for their civil engineering companies, readily

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* Published sources for this discussion are few and often contradictory The writer has perforce drawn extensively from the work of Middlemas (1975 and 1978) which is the most comprehensive published to date.

agreed to a loan of 560 million Francs (US $ 110 million)[273]. Germany despite some strong political protests from domestic groups, agreed to provide DM 400 million (US $ 95 million). Italy, however, approved export credits for the work to be undertaken by Societa Anonima Elettrificazione (SAE) but, under pressure from President Kuanda of Zambia, refused to honour this commitment claiming that no funds were available. Thereafter, SAE's work was funded directly from the Portuguese Treasury to the extent of 32 x 10^9 Lire (US $ 51 million). When the Swedish firm, ASEA, was forced to withdraw from the consortium, for reasons explained in Chapter 2, the German Siemens-AEG-Brown-Boveri group which took over the ASEA part of the contract obtained 7 million Rand (US $ 10 million) through the Industrial Development Corporation of the RSA. The German group had to raise the remaining US $ 20 million from commerical banks. The RSA, whose involvement has been discussed in more detail above, not only provided export credits for its own member companies within ZAMCO and the German group mentioned above, but also provided the full finance for that part of the d.c. transmission system lying in the RSA as well as agreeing to provide loans to Portugal totalling R 35 million (US $ 50 million) over four years, to cover debts incurred in the period before full output became available from the project[274].

There is a general lack of clarity in the information which has been published concerning the financing of the Cabora Bassa Project. In some cases no clear distinction has been drawn between the initial capital and the subsequent interest charges, whilst few, if any, accounts state whether the totals are given at current or constant prices or whether an allowance has been made for discounted costs over the life of the project. According to Middlemas, the value of the contract as approved in September 1969, was equivalent to US $ 340 million[275]. However, this figure does not include the cost of financing the loans, the initial allowance made for inflation (which in the event was too small) nor the full cost of the d.c. transmission line to the RSA. If all these are included the sum reaches US $ 600 million[276]. High inflation rates, delays and the effects of guerrilla activity brought the final total to over US $ 750 million. This figure, presumably includes the US $ 21 million allowed for resettlement in the initial contract but may not include later contracts for the building of intakes for the future North Bank Station and the construction of the 220 kV transmission line to link with the SHER grid at Chipata, which together cost US $ 35 million[277]. It is also unlikely to include the cost of the survey and design work undertaken by the MFPZ/GPZ which, from 1957 to 1970 was estimated to have cost 380 x 10^3 contos (US $ 13 million)[278].

On the basis of the original contract and the results of negotiations with ZAMCO over liability for the effects of inflation, the Portuguese authorities accepted liability, in 1975, for a total cost, including interest payments, which was estimated to be equivalent to about US $ 640 million at the time[279]. (The cost of the d.c. transmission system within the RSA is not included in this total). The Portuguese treasury provided directly about 10% of the cost, and the remainder comprised credits from France, Germany and the RSA as well as from commercial banks and financial institutions[280]. If the cost of the transmission system within the RSA is included it is clear that the RSA's financial commitment to the project was greater than that of either France or Germany, individually, and was probably close to the combined export credits provided by these two governments[281].

The events leading up to creation of the Portuguese registered company, Hidroeléctrica de Cahora Bassa (HCB), to operate the Cabora Bassa Project, have been described in Chapter 2[282]. The 10% share of the project's finance which had been provided from the Portuguese Treasury was converted into a 10% shareholding in HCB which was transferred to the State of Mozambique at independence. Creditors to the State of Portugal (for the project) were given the option of becoming either creditors to HCB or shareholders. HCB and Frelimo agreed terms whereby HCB would operate the Cabora Bassa Project on the basis of a lease - the *Contracto de Concessão*. The company has been made responsible for all parts of the project - its operation and financing, the maintenance of its engineering works and equipment and the supply of power to the RSA for which it receives revenue at the rates set out in a separate agreement between HCB and Escom*. Whilst the Mozambican authorities

*Responsibility for any renegotiation of these rates rests with HCB and not with Mozambique, see *Contracto de Concessão*, Article 10.

monitor the company's activities, and are involved in certain aspects of the hydrological operation of the dam, they receive no direct revenue nor have they a right to levy taxes on the company or its employees. However, Mozambique's shareholding in the company is increased annually as shares are redeemed from other shareholders; the transfer is reported to be scheduled at a rate of 3% of total stock per year[283] but this does not appear to have been laid down in the formal agreements. The *Contracto de Concessão* (Articles 5 and 6) states, simply, that HCB's concession over the project will end three years after the company's financial obligations have been discharged. Thereafter, the State of Mozambique will be free to end HCB's concession or to draw up terms for renewal. Since the majority of loans were taken as export credits for a period of thirteen-and-a-half years, from the beginning of 1975[284], the earliest date at which the concession might end would appear to be 1992, unless repayments are accelerated*. Decisions to reschedule the original loans, slowness by HCB in redeeming other shareholdings or the need to seek new loans, including those for the construction of a North Bank Station, would, automatically, postpone the date at which the concession would end; an outcome which would, presumably, be considered desirable by the present employees of HCB. Delay might also be beneficial to other shareholders, including the Government of the RSA, since the *Contracto de Concessão* makes provision for *ex gratia* dividend payments on shares with the exception of those given to the State of Mozambique which carry no entitlement to dividends until the initial concession period has ended.

If the terms of these agreements have been correctly interpreted, HCB appears to have a considerable degree of flexibility in its handling of the project's financing. Since a number of the options open to HCB would not, necessarily, be in the best interests of Mozambique it is essential for the company's financial transactions to be monitored. Unfortunately, this was not possible for at least the first four years of the operation because HCB failed to produce annual reports and accounts[285]. Nevertheless, should disputes arise about the terms of the concession or the adherence to it by either party an arbitration

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* With transfer of shares at a rate of 3% per year the concession would not end until 2008.

tribunal may be called, the procedures for which are also specified in the terms of the original agreement.

As stated above, Mozambique receives no direct revenue from the sale of electrical power to the RSA. However, the price paid by Escom to HCB affects the rate at which loan repayments can be made by HCB and, therefore, affects the date at which HCB's concession will end. According to the agreement of 1969, electrical energy was to be sold to Escom at a price of 0.0030 R/kWh, for a period of twenty years, falling to 0.0020 R/kWh, or less, for a further fifteen years[286] (approximately US $ 0.0042 and US $ 0.0028, respectively, at 1969 exchange rates). Despite suggestions, following independence, that a substantial increase in these rates was being negotiated, the present price appears, from the data in Table 27a, to be no higher than 0.0038 R/kWh which, at the present rate of exchange is about US $ 0.0043 /kWh - almost identical with the 1969 price. The revenue from sales is also given in Table 27a and can be seen to total about US $ 140 million over the five years. Under the present contract sales should

Table 27a: Estimated value of power sales to Escom

Year	Total Energy (TWh)	Total Revenue (Rand x 10^6)	Apparent Mean Cost (R/kWh)	Total Revenue (approx. equivalent) (US $ x 10^6)
1976	1.23	2.4	0.0020	3
1977	4.24	15.5	0.0037	18
1978	6.92	26.4	0.0038	30
1979	10.39	36.1	0.0038	43
1980	9.66	35.8	0.0037	43

Source: Escom Annual Reports*

by now have increased to 13.6 TWh/yr, at the Apollo substation, which would provide a revenue of US $ 60 million/yr. Allowing for maintenance and wage costs, and assuming that this level of output could be maintained, the debts could be fully discharged by about the year 1990 thus

* The figures include small amounts of power imported to the RSA from other sources but their effect on the present calculations is negligible.

allowing renegotiation of the concession in 1993. The payment of enhanced dividends to shareholders or interruption of the supply to Escom would delay the date of renegotiation. Since December, 1980, repeated sabotage of the d.c. transmission line has occurred[287]; the supply was frequently interrupted in the first seven months of 1981 and there were reports that, as a result, Escom had suspended its agreement to buy power from Cabora Bassa by August of that year[288]. The situation since that time has not been widely reported but, presumably, as soon as a reliable supply can be restored the purchase of power will proceed.

The present tariff agreement appears to be extremely favourable to Escom. In 1969, when the original contract was signed, the mean price of electrical energy sent out by Escom, according to its 1980 *Annual Report*, was 0.0056 R/kWh against an import charge of 0.0030 R/kWh for Cabora Bassa's energy. Since then, Escom's average price per unit sent out has steadily risen until it now stands at over 0.0200 R/kWh against the rate for Cabora Bassa's energy of 0.0038 R/kWh. It is, perhaps, more accurate to compare the Cabora Bassa tariff solely against Escom's fuel costs since Escom's transmission, administration and investment costs may not be appreciably lower as a result of the Cabora Bassa contract. Thus, in 1969, Escom's mean fuel costs were 0.0014 R/kWh whereas, by 1980, they stood at 0.0055 R/kWh. The data of Table 27b provide an estimate of the savings, in fuel costs alone, which Escom made, from 1976 to 1980, through its purchases of electrical

<u>Table 27b: Savings in fuel costs by Escom through the purchase of energy from Cabora Bassa</u>

Year	Energy purchased (TWh)	Cost of energy purchased ($R \times 10^6$)	Escom's mean unit fuel costs (R/kWh)	Equivalent fuel cost of energy purchased ($R \times 10^6$)	Expenditure saved by energy purchases ($R \times 10^6$)
1976	1.23	2.4	0.00314	3.9	1.5
1977	4.24	15.5	0.00356	15.1	-0.4
1978	6.92	26.4	0.00382	26.4	0
1979	10.39	36.1	0.00422	43.9	7.8
1980	9.66	35.8	0.00547	52.8	17.0
				Total 1976-80	25.9

Source: Escom Annual Report, 1980, p56-59.

energy from Cabora Bassa. Even on the unlikely assumption that Escom's fuel costs will rise no further in the next few years, the savings in fuel costs alone would be enough to repay the capital and interest costs of the investment, which the RSA made in the d.c. transmission line and the Apollo substation, in about another four years. Thereafter, at full output, savings in excess of R 20 million/yr could be made by the continuing purchase of energy from Cabora Bassa.

Although tariff renegotiation is not necessarily in the best interests of HCB, it was reported[289] in January, 1982, that the Portuguese Government, which ultimately remains responsible for the outstanding debts, was seeking a new agreement with Pretoria over payments to HCB for energy from Cabora Bassa. Such a renegotiation would clearly be in Mozambique's best interests. On the other hand, Escom is unlikely to volunteer to increase the tariff, as the Governments of Portugal and Mozambique would have little power to compel such a change, unless recourse can be made to additional international pressure on the RSA. Escom's original motives for entering the agreement with Portugal were based on the political factors, discussed in Chapter 2, as well as on technical and economic considerations. This may be seen in the benefits identified by Olivier (1973): cheap energy; water conservation (the equivalent output from a thermal station requires 140×10^3 m^3/day for wet cooling towers); and supplementation of thermal sources in the period before nuclear power could be introduced. Although the RSA still derives benefits in each of these respects from the purchase of energy from Cabora Bassa, provided that the supply is reliable, Escom has always been careful to avoid heavy dependence on an interruptable source. In the short-term, loss of the supply would increase Escom's costs and might cause minor power cuts[290]. However, reserve capacity, in the form of old less efficient thermal generation, is available to cover the ten per cent of Escom's sales purchased from Cabora Bassa. Moreover, in the terms of the original agreement, as reported by Middlemas (1975), there were penalty clauses which protected Escom against increased costs due to loss of supply:

> The agreement, signed in August 1969 provided (*inter alia*) that two monopolar lines would be erected, and that if one fell out of commission 80 per cent of the current had to be

directed through the other, with earth return. If power fell below the 80 per cent load factor there was a penalty of three times the cost per megawatt hour if in peak load time, and of less if at any other time. Destruction by *force majeure* would have provided temporary relief from this penalty. (p85)*

Alternative markets for the energy from Cabora Bassa

Throughout the period of planning which preceded the construction of the Cabora Bassa Dam attempts were made to find alternative consumers for the project's output from amongst the countries bordering on Mozambique, particularly Rhodesia (Zimbabwe). The idea of exporting energy to Rhodesia was made at an early stage, see Appendix 4, but was then shelved following a visit to Salisbury, in 1961, by members of the MFPZ who reported that:

> The Federation is not at present interested, nor does it appear as if it will be interested, in the consumption of electrical energy produced from the Zambezi or its tributaries in Mozambique[291].

Following the break-up of the Federation and the imposition of UN economic sanctions, following UDI, fresh contact was made between officials in Rhodesia and the Portuguese authorities. In the event, these talks also failed to produce agreement. Vidigal (1970) reported that there were no immediate plans to supply Rhodesia or Zambia with energy although he believed that, in the long-term, energy would be supplied to Rhodesia in view of the fact that Cabora Bassa is very little further from Harare than is Kariba. The final agreement with Escom, however, restricted such sales as regards the output from the South Bank Power Station.

Since the country's independence the authorities in Zimbabwe have again shown themselves interested in the possibility of constructing an inter-connected regional electricity supply network and in

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* It would be interesting to know whether the recent incidents of sabotage of the transmission line have been interpretted as '*force majeure*', particularly in view of the widespread belief amongst officials in Mozambique, and a number of independent observers, that the guerrillas who undertook the raids are supported by, and trained in, the RSA.

purchasing power from Cabora Bassa. One of the eight accords between the governments of Mozambique and Zimbabwe on the occasion of President Machel's visit to Harare in August, 1980, stated:

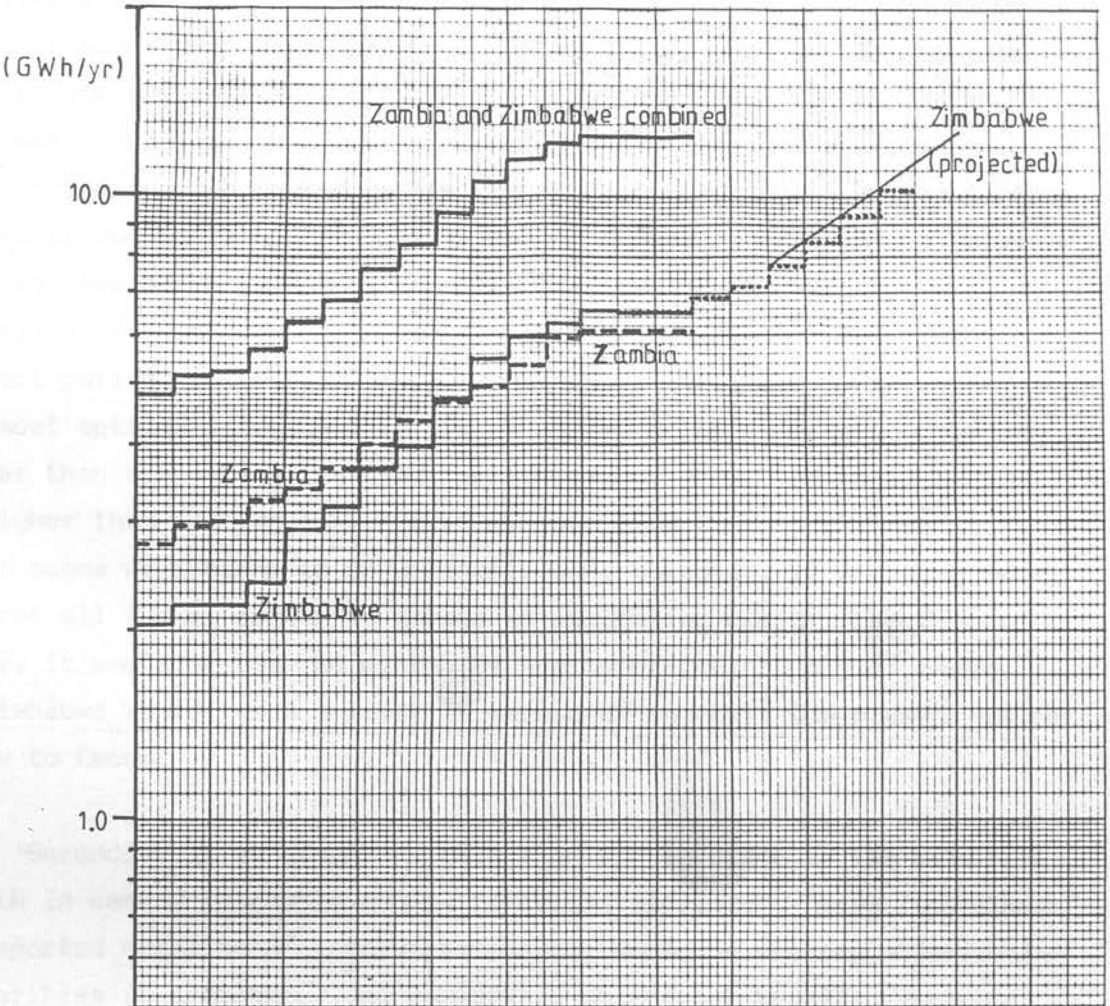
> In the field of Energy, Mozambique and Zimbabwe will gather information relating to the development of the electrical energy sector taking account of the principle of complementarity and rational utilization of human and material resources. The two countries will study the best way to optimize their respective hydroelectric resources with particular attention to the potential of their contiguous hydrographic basins.
>
> Some of the work for the inter-connection of the electricity networks between the two countries has already been started and the viability of further lines will be studied.
>
> In the conversations, Mozambique informed Zimbabwe that it is going to begin Phase Two of Cabora Bassa and both sides agreed that it is viable to use energy from Cabora Bassa in Zimbabwe[292].

The possibility of supplying power to three neighbouring countries is considered in more detail below in the light of the statistics, presented in Figure 37, for the total consumption of electrical energy in these three countries from 1964 to 1979.

a) Zimbabwe: Although Zimbabwe provides by far the most promising market for power from Cabora Bassa it is clear that it could not provide an immediate alternative market for the power sold to Escom, if such an alternative were needed at some future date. Nor could Zimbabwe be relied on to take sufficient energy to ensure the economic success of the proposed North Bank Station. With the transmission link in existence, via Mutare, Zimbabwe could already import up to 100 MW of power from Cabora Bassa, if it were available, but it would be unlikely to take substantially more power in the near future, even if the necessary transmission lines were built. The reasons for this are easily identified.

Firstly, the market in Zimbabwe is small relative to the output of Cabora Bassa. In 1956, when final plans for the Kariba Project were being prepared, an official report[293] predicted that consumption of electrical energy in Zimbabwe and Zambia would increase at a rate

Figure 37: Gross consumption of electrical energy in Zimbabwe, Zambia and Malawi, 1964-1979.



Source: UN (1976, 1978 and 1981), see also notes 294 and 300.

of 8% until 1971 with consumption in Zambia remaining higher than that in Zimbabwe. The prediction was remarkably accurate up to 1967 when the consumption in Zimbabwe was 2.4 TWh/yr and that in Zambia 3.2 TWh/yr. Thereafter, however, under the stimulus to its economy provoked by UN economic sanctions, consumption in Zimbabwe rose by over 12% per year causing the combined consumption of the two countries to rise at 10.5% per year. This growth slowed considerably in the mid-1970s when the economic disruption caused by the war in Zimbabwe finally halted further growth in consumption. At that time, the annual consumption in Zimbabwe, 6.5 TWh, was slightly higher than that in Zambia. It was predicted shortly after independence that consumption in Zimbabwe would, within a short period, resume its previous pattern of growth[294]. Nevertheless, the most optimistic estimates foresaw an annual rate of consumption no higher than 8.5 TWh/yr, by 1982, and a rate of growth of consumption no higher than 10% per year. Even if such predictions are correct, which seems at present to be unlikely, and, moreover, if Zimbabwe were to meet all future growth in demand by purchasing energy from Cabora Bassa, it would be the end of the decade before the supply of energy to Zimbabwe would reach a level in excess of one-half the present energy sales to Escom.

Secondly, it is almost certain that the solution to the expected growth in demand suggested above, involving increasing heavy dependence on imported supplies of electrical energy, would be unacceptable to the authorities in Zimbabwe. The country is at present heavily dependent on energy imported from Zambia; in the period from 1977 to 1980 between 2.5 and 3.0 TWh/yr were imported - accounting, in one year, for over 45% of the energy consumed[295]. Despite having a relatively high degree of control over this supply, through the operation of the inter-connected CAPC grid, officials in Zimbabwe were unhappy about such heavy dependence on imported energy and have, apparently, resolved to import no more than 15% of the country's total consumption in future[296]. Moreover, if Zimbabwe were to import even this proportion of its consumption it would require guarantees that the supply would not be interrupted either through technical failures or through sabotage attacks similar to those in Mozambique on the d.c. transmission line. This might involve additional investments in duplication of the main transmission links which would add considerably to the cost of the energy.

Thirdly, and decisively, Zimbabwe is now committed to obtaining its future energy requirements from domestic sources. Phase One of the power station near to the Wankie coal mine is under construction and is expected to add 480 MW of generating capacity to the national grid by the beginning of 1983*. Further contracts are now believed to have been signed for the construction of Phase Two of this project which will add a further 1 200 MW by the middle of 1985. In addition, further hydroelectric projects on the Zambezi are being actively investigated as described in Chapter 2. The Zimbabwe supply system would then have adequate internal sources for both base-load and peak-load energy.

Under these circumstances it is extremely unlikely that Zimbabwe would agree to purchase energy from Cabora Bassa in the near future.

b) <u>Zambia</u>: Many of the above observations concerning the sale of energy from Cabora Bassa to Zimbabwe also apply to Zambia[297]. However, the rate of growth of consumption of electrical energy in Zambia has not been as high as that in Zimbabwe although from 1964 to 1975 a steady growth of 7% per year occurred. Higher growth rates have also been inhibited by the low income level of the majority of the population and the lack of diversification of the economy. For example, for the year 1977/78 over 55% of consumption was accounted for by sales to the Copperbelt Power Company[298]. Energy demand is, therefore, strongly affected by the level of output from the copper mines. Furthermore, Zambia is unlikely to meet the foreseeable growth in demand by purchasing energy from Cabora Bassa: for a number of years it will be able to use output at present exported to Zimbabwe; it will also benefit from any new hydroelectric projects which may be built jointly with Zimbabwe on the Zambezi; a further stage of the Kafue Project could also be built; and, thereafter, should Zambia wish to import energy, it could do so more readily over the existing 220 kV a.c. link with the Shaba

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* This project was begun secretly during the period of UDI but was stopped following the discovery of agreements with French and German firms to supply equipment in contravention of the UN sanctions.

Province in Zaire, which is now receiving power along a d.c. transmission line from the Inga Project[299].

c) Malawi: A glance at the present level of consumption of electrical power in Malawi, see Figure 37, shows that there is no prospect of it importing large blocks of power from Cabora Bassa for the foreseeable future. Moreover, the country has considerable untapped hydroelectric resources of its own which could be developed as required, provided that the necessary capital is available[300]. The original suggestion, prior to Mozambique's independence, that Malawi might import power from Cabora Bassa was made in connection with the proposal, later rejected, to build an aluminium smelter on the Shire, as recounted earlier in this chapter.

The options open to Mozambique

At the beginning of this chapter the Portuguese proposals for mineral exploitation in the Zambezi valley were examined. It was concluded that the plans were unrealistic in view of the lack of accurate survey information, the remoteness of the region, the lack of adequate transport facilities and the lack of consideration which had been given to the social, political, environmental and economic consequences of similar projects in other underdeveloped regions. Special study was also made of possible energy intensive processes* but, here too, the projects envisaged by the MFPZ appear to offer no guarantee, at present, of achieving rapid economic growth, of providing a base for further industrialization or of stimulating the growth of the electricity supply industry. In particular, the plan to establish an aluminium smelter in the Zambezi valley, which is the project in which the present authorities have shown greatest interest, appears, on the basis of experience in other underdeveloped regions, to offer very limited benefits. At the same time, it would impose considerable constraints on the Government's freedom to exercise control over the national economy and to achieve its stated social and political objectives.

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* Portuguese interest in such projects was based on the need to provide finance for the Cabora Bassa Project. This motive was removed with the signing of the power agreement with Escom.

Selected case studies of the growth of electricity supply systems in other regions suggest that the supply of cheap electricity, by itself, is not a sufficient precondition for rapid industrial development even when adequate security and reliability of supply can be assured. Furthermore, attempts to achieve a rapid growth in the demand for electrical energy, either through attracting energy-intensive processes or by exporting power to neighbouring regions, have, rarely brought long-term benefits to the economy of the energy producing region. The exception to this, amongst the cases considered, is the Province of Quebec, but the circumstances which brought successful industrial development to that region are very different from those which pertain in Mozambique today.

From a detailed study of the development of the electricity supply industry in Mozambique, and study of various factors governing the operation and development of the Cabora Bassa Project, two important questions arise which may or may not be interrelated:

1. How can Mozambique derive the maximum benefit from the Cabora Bassa Project; and
2. How can the projected increase in demand for electrical energy within Mozambique be met?

An attempt might be made to treat the two issues entirely separately. In this case the basic agreement to supply Escom from Cabora Bassa might well be justified. This does not exclude the possibility of Mozambique attempting to modify certain aspects of its agreement with HCB and, in particular, the contract between HCB and Escom, the energy tariff and the aspects of the project's hydrological operation, such as flood control, which are discussed in other parts of this thesis. However, to achieve even these changes would require a measure of co-operation between the principal parties, since Mozambique could do little to impose such changes. The supply of power to consumers in Mozambique requires new initiatives to be made in the near future. Maputo and the southern region require either a new thermal power station or a further agreement to import power from Escom; Beira and the central region could probably be supplied by further development of the region's hydroelectric resources; and the northern region could be supplied from a combination of small hydroelectric and thermal power stations. With the new transmission line from Songo to Mocuba in operation the region surrounding that line could be supplied from a single coal-fired power station at Moatize, but over-reliance on a single source for the northern region would be unwise because of the vulnerability of such a supply to system failures. If isolated power stations were built with local distribution systems, these could be inter-connected at a later date to create an efficient and reliable supply network.

An approach could be made to Escom to seek a reduction in the level of output supplied to it under the terms of the Cabora Bassa contract. If in the initial stages, Escom were simply to relinquish its entitlement to peak power, this would allow Mozambique to obtain up to 100 MW from the project as indicated by the results of Simulation 4 in Chapter 3. However, since this would increase the risk of lost output should one of the project's generating sets require repair or maintenance, Escom might also be called upon to agree to Mozambique being given first preference over the remaining output from the project during periods of shortage. Such an arrangement might be operated under the existing contract on the payment of agreed compensation but the price paid by Mozambique for its energy might then be prohibitively high. For the supply of power to northern Mozambique, the transmission line could be extended beyond Mocuba, creating an elongated transmission system supplied by a single source of generation located at one end, but this would bring with it the risk of a single fault causing wide-spread loss of supply.

The situation might arise whereby no further power would be supplied to Escom from Cabora Bassa by action on either side. For Mozambique to take such action would be unwise since there is no prospect in the foreseeable future for alternative markets to be found for more than a small fraction of Cabora Bassa's output. In addition such action would, almost certainly, evoke retaliation from the RSA in the form of halting the export of power to Maputo, which would be exceedingly damaging to the economy of Mozambique. On the other hand, the RSA might act to end its purchases of power from Cabora Bassa, either directly or indirectly through support for saboteurs, without sustaining excessive or prolonged damage to the operation of the Escom system. Clearly, if Escom were to cease buying power from Cabora Bassa there would be an abundant output available for consumption in those parts of central and northern Mozambique which could be readily connected to a centralized distribution network. Nevertheless, even if consumption could be increased dramatically Mozambique would have no direct means of earning the hard currency needed to repay the outstanding loans.

The North Bank Power Station at Cabora Bassa might be built; it has been reported[301] that Sweden had agreed to finance the North Bank Station provided that Zimbabwe would agree to purchase its output. Such an arrangement would have allowed the operation of the South Bank Station to continue on the basis of existing agreements whilst the new station would provide sufficient excess power to supply demand in northern Mozambique, albeit through the existing unsatisfactory transmission system. Furthermore, in due course, large markets for power, linked to Cabora Bassa, would have been established which would have been capable of using output from the South Bank Station should the power supply to Escom have been halted. Recent power supply policy decisions in Zimbabwe have prevented the project from proceeding in this way. Mozambique cannot, at this stage, contemplate building the North Bank Station, even with sequential expansion of the installed capacity in line with demand, because the investment needed for the initial excavation of the power house and water conduits would be prohibitive.

It is clear that Mozambique is entirely dependent on the RSA regarding the operation of the Cabora Bassa Project. On balance it seems likely that both countries will favour a continuation of the supply of power to Escom: Mozambique, despite its wish to reduce its dependence on the RSA would fear losing the supply to Maputo and would be placed under strong pressure from France, Germany and Portugal if investments in the project could no longer be repaid; the RSA would not only welcome Mozambique's continued dependence but would wish to see its own investments in the project repaid and to continue obtaining the very cheap energy which Cabora Bassa provides. It seems doubtful, however, that any substantial renegotiation of the terms of the agreements governing the operation of the project could be achieved at present. Furthermore, it is unlikely that the North Bank Station will be built in the near future*.

In respect of the supply of electrical energy to consumers inside Mozambique it appears that, for the foreseeable future, it would be best to plan the country's power systems entirely independently from the Cabora Bassa Project. There appears to be no particular economic or political virtue, at this stage, in seeking to promote energy-intensive industries although modest amounts of power would be required if some or all of the plans for the following are implemented: textile manufacture, fertilizer production, timber and paper industries, and steel production in small electric-arc furnaces. The northern region is likely to remain relatively underdeveloped for a long time but the development process will not necessarily be speeded up by the creation of an inter-connected electricity supply network at this stage. Gradual development of smaller local generating units will lead, in the long-term, to a more balanced and manageable network and probably provide more linkage benefits, including training opportunities for Mozambican staff, than would the centralized system which has been proposed.

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* It has been suggested that Escom might agree to buy increased amounts of energy from Cabora Bassa if the North Bank Station were built particularly if, as du Toit (1975) foresees, Escom begins generating base-load energy from nuclear fuel. Cabora Bassa could then provide increasing amounts of peak energy. However, it is very unlikely that such an agreement would be made in the present political climate. In addition the project would require a new transmission line and a change of operating procedures from base-load to peak-load which would have considerable impact on the river downstream.